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Title: Risk and Reliability Associated with Use and Reuse of Vertical Formwork

Abstract approved:

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Concrete formwork is a common type of temporary structure used on construction projects. Due to difficulties in considering actual construction site implications during formwork design, assessments of formwork integrity are often made in the field by site personnel based on subjective visual inspection. The use and re-use of concrete formwork exposes the workers involved in formwork use to different types of injury. This research study aims at: (i) mapping a general site activity workflow for the use and re-use of vertical formwork; (ii) evaluating onsite safety risks associated with formwork use and re-use activities, and (iii) assessing the reliability associated with formwork use and re-use. Development of the mapped workflow and identification of safety risks associated with each activity were based on interviews of construction site foremen involved in formwork construction and jobsite observations of formwork construction activities. Based on results from the survey on 32 carpenters engaged in concrete work, worker risk associated with formwork activities was quantified. Erection, stripping, and assembly of formwork were found to be activities that contribute most to the cumulative risk. The worker perception on the safety risk was compared to the recorded Occupational Safety and Health Administration (OSHA) Fatality and Catastrophe summaries, which correspond to worker injury reports. Data collected from OSHA injury reports indicate that concrete pouring, erection, and stripping are the activities with the highest risk. This

shows a notable disconnect between survey based worker perception results and corresponding OSHA statistics. Sensitivity of unit risk indicate that high severity incidents have the highest impact on the risk, followed by Near Misses.

Comparing the capacity of formwork samples with different number of uses to estimated load demand, reliability assessments were performed. The reliability assessment results are mixed since a large bias and uncertainty in the computation of the loading and capacity were identified in the development of this study. The bias is related to overly simplified and over conservative design equations that are currently prescribed in design guides, while the large uncertainty is mainly due to inherent randomness in the material and influence of exposure to the concrete on the strength of the plyform.

Risk and Reliability Associated with Use and Reuse of Vertical Formwork

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Amrutha Das, Author

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CHAPTER 1. INTRODUCTION

1.1. BACKGROUND

Formwork has been used widely in construction practice since the discovery and establishment of Portland cement concrete as a favored building material. Concrete can be molded into desired shapes and dimensions using formwork, which is essentially a mold for the concrete. Formwork is a temporary structure that can be incorporated into the permanent structure or removed after the concrete has reached design strength. Formwork costs can constitute from 35 up to 60 percent of the concrete cost in projects involving large quantities of concrete work (Hurd, 2005; Lab, 2007).

There are many types of formwork available in the market for use depending on the application and location of use. The two most common types of formwork found in the Pacific Northwest are traditional, site-built timber formwork and engineered formwork systems. The former is the most labor and time intensive of the two, especially for projects with a large amount of concrete work. However, traditional timber formwork is also the most flexible out of all the different types of formwork and hence can be used to form sections with intricate architectural detail. Traditional timber formwork typically consists of plywood or timber sheathing, with timber members placed as studs and wales on the back of the formwork. Falsework such as braces or shoring may be used depending on the concrete member being formed. Engineered formwork is used very commonly due to its relative ease and speed of assembly. Engineered formwork systems consist of formwork panels with plywood or metal sheathing on an aluminum or steel frame, and can be connected with pins, clamps or screws. These prefabricated systems also have the additional advantage of lower overall costs and larger number of uses compared to traditional timber formwork.

Formwork is generally designed according to guidelines set by various associations or publications such as the American Plywood Association (APA), National Design Specifications for Wood Construction, and ASCE *Design Loads on Structures During Construction* manual (ASCE 37-02). Perusal of the more commonly available guidelines indicate that re-use of formwork is generally not formally factored into the design of formwork. Formwork is subjected to a wide variety of loads and exposures when in use, and it stands to reason that there would be a reduction in the strength or structural capacity of the formwork as it undergoes multiple uses. Reliability and risk related to formwork activities are also topics that are underexplored. Use of formwork often involves working at heights, and on temporary platforms, which are factors that affect the efficiency and safety of construction workers. In addition to this, activities such as stripping of formwork from concrete and assembling forms at site involve a certain amount of risk to the workers. The location of the activity as well as the activity itself affects the productivity of the worker as well as the safety of the worker, and these effects have not been considered so far, even by regulating agencies such as OSHA. Even though most of the issues such as fall protection, scaffolding, use of power tools etc. have been addressed in the OSHA 29 CFR 1926 by themselves, they have not been investigated from the perspective of formwork use. OSHA Fatality and Catastrophe Investigation Summaries give an idea of the various types of accidents associated with concrete formwork, as well as the causes of accidents associated with formwork use. There are no mandatory rules regarding the use and re-use of formwork, but just guidelines for use.

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1.2. OBJECTIVES

The main objectives of this study are to expand the construction industry’s understanding of formwork activities by mapping the typical use cycle of formwork on-site, identifying the primary factors contributing to risks and evaluating the risks posed to the workers caused by the execution of various activities that comprise the formwork cycle, and evaluating the reliability associated with formwork use and reuse. To reach these main objectives, multiple secondary objectives were established: to determine the main factors that impact formwork lifecycle on a project, establish a sequence of activities that represent an overall formwork cycle that can be easily modified to fit any project, identify the major causes of accidents related to formwork, evaluate the change in strength characteristics of formwork between uses and quantify risk associated with each activity in the established formwork cycle, which can be used to determine the overall risk associated with one formwork cycle.

The medium to long-term output from this research study is expected to be a formwork use model, which accounts for deterioration of the formwork as the number of uses increases. The formwork use model would also include risk values for each use cycle, with the risk values increasing as the deterioration increases with the number of uses.

1.3. THESIS OVERVIEW

Multiple tasks were carried out in order to meet the objectives of this research. First, interviews were conducted in order to gain insight into the factors that affect the lifecycle of formwork during real-time construction activities, as well as to develop an understanding of the formwork use cycle. Next, projects with some amount of concrete work were chosen so that formwork use could be monitored through the project and samples obtained for estimating possible degradation. A safety survey has also been developed and was carried out in an attempt to quantify the risks associated with formwork activities.

This thesis consists of six chapters:

Chapter 1: Introduction

Chapter 1 covers the following three topics: background of the research study, objectives, and an overview of the thesis.

Chapter 2: Literature Review

Chapter 2 consists of short overviews of a selection of past work and research deemed relevant to this thesis, and consists of three subsections: formwork design (allowable loads and capacities), formwork use and re-use, risk assessment, and reliability assessment.

Chapter 3: Methodology

Chapter 3 explains the methods used for obtaining information, monitoring the formwork cycle, testing samples, identifying safety concerns associated with formwork, as well as methods used in reliability assessment of the formwork.

Chapter 4: Formwork Monitoring and Testing

Chapter 4 contains detailed explanations of the results of the formwork questionnaire, onsite formwork monitoring, OSHA case study results, and the laboratory testing undertaken.

Chapter 5: Risk and Reliability Assessment

Chapter 5 presents the results obtained from the safety risk survey, the subsequent risk model, and the reliability assessment performed.

Chapter 6: Conclusion

Chapter 6 summarizes the main conclusions of this research, and includes a discussion of the limitations as well as recommendations for further study.

CHAPTER 2. LITERATURE REVIEW

The following literature review is divided into sections describing the background with which this research study was initiated, and contains an overview of the formwork design process, loads considered in the process, allowable capacities of formwork, formwork use and re-use, and risk assessment and reliability assessment.

In this section, numerous references to the term formwork components are used to specify individual members that are combined to constitute traditional formwork, such as plywood, and dimensional lumber that form the sheathing, studs, whalers, braces, etc. Figure 2.1 shows a wall form panel assembled and erected, ready for the placement of concrete. Sheathing is the surface of the formwork directly in contact with the concrete. Figure 2.1 shows plywood sheathing as well as board sheathing. Form liners can also be placed on the sheathing so as to obtain specific architectural finishes. Studs, joists and whalers act as supporting members to the sheathing and resist the lateral load. Different types of hardware - taper ties, nails, screws, bolts, clamps etc. – are used as connectors in the system. Ties and spreaders are used to maintain a constant gap between the panels for uniform thickness of the structure. Sills or plates help to fix the formwork panel on surfaces, and prevent leakage of concrete from the form. Braces are used to provide additional support and resist wind or seismic loads.

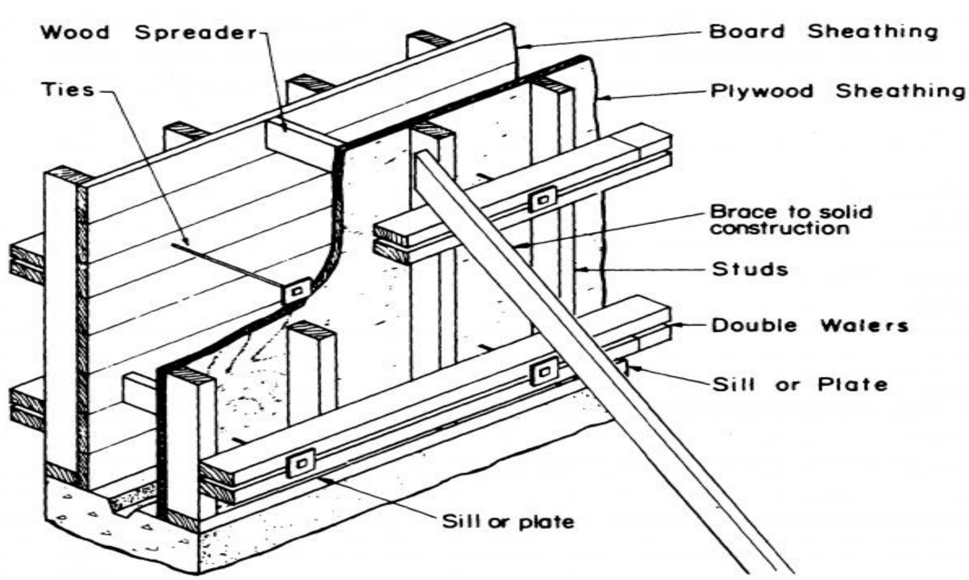


Figure 2.1: Formwork components (Hurd, 2005)

2.1. FORMWORK DESIGN AND LOADS CONSIDERED

The typical design procedure for formwork is adapted from *Formwork for Concrete* (Hurd, 2005). For vertical formwork, specifically walls and columns, the lateral pressure on the formwork is calculated using the various formulae based on specific conditions such as concrete properties, rate of pour, temperature of mix, and height of the design member in consideration. Wind loads and any additional loads other than the lateral load applied by the placement of concrete are assumed to be resisted by the bracing or shores. Information regarding loads other than lateral pressure exerted by concrete, and various load combinations can be found in the *National Design Specification for Wood Construction* (AWC, 2005) and *Design Loads on Structures During Construction* (ASCE, 2002). The calculation of lateral pressure is discussed in detail in this subsection.

For column formwork (Hurd, 2005), pressure P on the forms due to the placement of fresh concrete is calculated by the formula

$$P = \gamma H \tag{2.1}$$

where:

- P = Pressure in lb/ft^2
- γ = Unit weight of the concrete mix in lb/ft^3
- H = Height of concrete placement in ft

For concrete mixes with a slump of 7 inches or less, and for a depth of internal vibration of 4 feet or less, the following formula can be used to calculate the pressure P:

$$P_{col} = C_C C_W \left[150 + 9000\frac{R}{T}\right] \tag{2.2}$$

where:

- C_C = Chemistry coefficient, values can be found in Table 2.1
- C_W = Unit weight coefficient, values can be found in Table 2.2
- R = Rate of placement of concrete measured in feet/hour
- T = Temperature in degrees Fahrenheit

The pressure P that the form is subjected to should be taken between a minimum pressure of $600C_W$ and a maximum pressure of γH under these conditions. For the purpose of determining pressures, columns are said to be structural members with plan dimensions less than or equal to 6.5 ft.

Table 2.1; Chemistry Coefficients, C_C (Hurd, 2005)

Cement type or blend	**Chemistry coefficient C_C**
Types I, II, and III cements without retarders	1.0
Types I, II, and III cements with a retarder	1.2
Other types or blends containing less than 70%slag or 40% fly ash without retarders	1.2
Other types or blends containing less than 70% slag or 40% fly ash with a retarder	1.4
Blends containing more than 70% slag or 40% fly ash	1.4

Table 2.2: Unit Weight Coefficient C_W (Hurd, 2005)

Unit Weight of Concrete	**C_W**
Less than 140 lb/ft^3	C_W = 0.5[1 + (w/145 lb/ft^3)]
140 to 150 lb/ft^3	1.0
More than 150 lb/ft^3	C_W = w/145 lb/ft^3

For the design of wall formwork (Hurd, Formwork for Concrete (SP4), Seventh Edition, 2005), two equations are considered when concrete mixes with a slump of 7 inches or less are used, and when the depth of internal vibration is 4 ft or less.

First, when rate of placement *R* is less than 7 ft/hr, and height of placement *H* is 14 ft or less,

$$P_{wall} = C_C C_W \left[150 + 9000\frac{R}{T}\right] \quad (2.3)$$

When rate of placement *R* ranges between 7 ft/hr and 15 ft/hr, or if rate of placement *R* is less than 7 ft/hr and height of placement H is greater than 14 ft, the maximum lateral pressure is calculated by:

$$P_{wall} = C_C C_W \left[150 + \frac{43400}{T} + 2800\frac{R}{T}\right] \quad (2.4)$$

The value of this pressure is still subjected to a maximum of γH and a minimum of $600C_W$. For any conditions that exceed those specified above, the design pressure is calculated by using the equation (2.1): $P = \gamma H$.

It is to be noted that equations (2.2) and (2.3) are the same, even though the former is used for columns, while the latter is conditionally used along with equation (2.4) for the calculation of lateral pressure on wall formwork.

While *Formwork for Concrete* (Hurd, 2005) is the document most widely in practice to determine the loads on formwork as well as for formwork design, a recent study (Barnes & Johnston, 2003) measuring the lateral pressure exerted by fresh concrete has indicated that equation (2.3) for walls is to be eliminated as it underestimates the pressure, even if it meets the equation constraints, i.e. the rate of placement is less than 7 ft/hr (Barnes & Johnston, 2003). Additionally, this study recommends that equation (2.4) be used without the rate of placement limitation instead of equation (2.3), so as to provide a more conservative estimate of the lateral pressure. Research studies comparing the calculated pressure as per Equations 2.1, 2.2, 2.3 and 2.4 to the actual lateral concrete pressure exerted on formwork indicate that the calculated pressure value is not close to the measured pressure value (Gardner, 2014)

For slab formwork or horizontal formwork, the design load is determined as the sum of the actual dead load on the formwork, which includes the self-weight and weight of the concrete and reinforcing steel which is to be placed on it, plus additional loads such as construction live load and equipment/personnel load as specified by ASCE 37-02: Design Loads for Structures under Construction (2002). Since horizontal formwork has a different loading pattern compared to vertical formwork, its design procedure and loading conditions fall outside the scope of this study.

After obtaining the lateral pressure in lb/ft^2 using the appropriate formula, the load per unit foot w (plf) is calculated considering a strip of formwork 1 foot wide. For any given timber wall or column formwork system, the allowable bending stress, shear and deflection are checked so as to ensure that the load demand on the formwork, as calculated using the pressure formulae, is below the allowable capacity of the given system. If it is found that the load demand is greater than the allowable capacity of the given arrangement, the arrangement is revised, either by increasing the size or thickness of the various components that constitute the arrangement, or by decreasing the spacing of the joists and stringers.

2.2. ALLOWABLE CAPACITY OF FORMWORK

The allowable capacity of formwork, i.e., the allowable maximum bending stress, shear stress, and deflection, is calculated using tabulated design values from the *Formwork for Concrete* (Hurd, 2005), and by using various adjustment factors depending on the design philosophy adopted. In timber design, either Allowable Stress Design (ASD) or Load and Resistance Factor Design (LRFD) can be used. For the purpose of this study, design has been performed using ASD adjustment factors. A brief explanation of the different adjustment factors applicable to formwork design using ASD can be found in the following paragraphs, as mentioned in the National Design Specification for Wood Construction (National Design Specification for Wood Construction, 2005). For the purpose of this section, the following notations denote the respective reference design properties/values:

- F_b / F'_b = Allowable bending stress / Factored allowable bending stress
- F_c / F'_c = Allowable compression stress parallel to the grain / Factored allowable compression stress parallel to the grain

- $F_{c\perp}$ / $F'_{c\perp}$ = Compression stress perpendicular to the grain / Factored compression stress perpendicular to the grain
- E / E' = Modulus of elasticity / Factored modulus of Elasticity
- F_v / F'_v = Allowable shear stress / Factored allowable shear stress
- F_t / F'_t = Allowable tensile stress / Factored allowable tensile stress

Load Duration Factor (C_D):

The load duration factor accounts for the relationship between the strength of the formwork component, and the time the component spends under loading. It is applicable to all reference design values except modulus of elasticity (E) and compression perpendicular to grain. The value of C_D increases as the duration of loading decreases. For construction loading, a factor of 1.25 corresponding to a duration of 7 days is typically used. Other values of C_D for different durations of loading are presented in Table 2.3. When loads of different duration are applicable, the C_D for the shortest duration of load is used for calculation purposes.

C_D is calculated from the Madison curve, developed by the Forest Products Laboratory. The curve can be seen in Figure 2.2.

Table 2.3: Load Duration Factors C_D (AWC, 2005)

Load Duration	**C_D**
Permanent	0.90
Ten Years	1.00
Two months	1.15
Seven Days	1.25
Ten Minutes	1.60
Impact	2.00

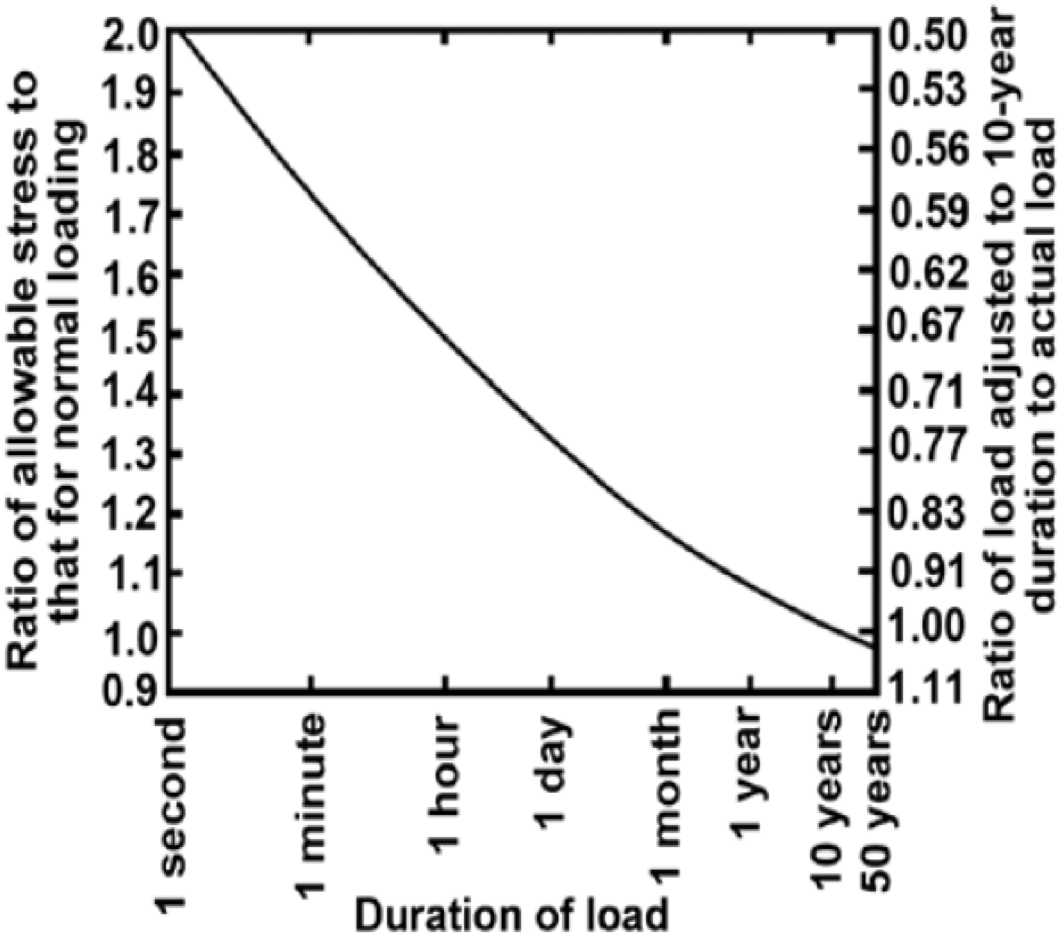


Figure 2.2: Relation of Strength to Duration of Load, C_D (Forest Products Laboratory, 2010)

Size Factor (C_F):

The size factor is used to adjust the tabulated allowable bending, tension, and compression parallel to the grain values for dimensional lumber, and is calculated using the provisions given in ASTM D1990. For members 2” to 4” thick, C_F is selected as per Table 2.4. The size factors are different for dimensional lumber 5”x5” and larger, but these sizes are not typically used as formwork components.

Table 2.4: Size Factors for 2” to 4” thick dimensional lumber (AWC, 2005)

		F_b		F_t	F_c
Grades	**Width (depth)**	**Thickness (breadth)**			
		2” & 3”	**4”**		
Select Structural No.1 & Btr, No.1, No.2, No.3	**2”,3”, & 4”**	1.5	1.5	1.5	1.15
	5”	1.4	1.4	1.4	1.1
	6”	1.3	1.3	1.3	1.1
	8”	1.2	1.3	1.2	1.05
	10”	1.1	1.2	1.1	1.0
	12”	1.0	1.1	1.0	1.0
	14” &	0.9	1.0	0.9	0.9
Stud	**2”,3”, & 4”**	1.1	1.1	1.1	1.05
	5” & 6”	1.0	1.0	1.0	1.0
	8” & wider	Use No.3 Grade tabulated Reference design values and size factors			
Construction, Standard	**2”,3”, & 4”**	1.0	1.0	1.0	1.0
Utility	**4”**	1.0	1.0	1.0	1.0
	2” & 3”	0.4	---	0.4	0.6

Flat Use Factor (C_{fu}):

Flat use factors are used to adjust the allowable bending stress values if the member is used edgewise, i.e., load is applied to the narrow face of the member, by multiplying the tabulated design value by the flat use factor shown in Table 2.5. This adjustment factor is calculated using the 1/9 power size equation in ASTM D245, and should be used cumulatively with the size factor C_F. It is to be noted that the flat use factor for dimensional lumber 5"x5" and larger are different, but these sizes are not typically used as formwork components.

Table 2.5: Flat Use Factors, C_{fu} (AWC, 2005)

Width (depth)	**Thickness (breadth)**	
	2" & 3"	**4"**
2" & 3"	1.0	---
4"	1.1	1.0
5"	1.1	1.05
6"	1.15	1.05
8"	1.15	1.05
10" & wider	1.2	1.1

Wet Service Factor (C_M):

The wet service factor accounts for the variability in the strength of wood caused by fluctuations in its moisture content, and is calculated from ASTM D1990 (7) and ASTM D245. When the formwork components are used where the moisture content is known to exceed 19% for an extended period of time, the appropriate wet service factor should be used as specified in Table 2.6. It is to be noted that the wet service factors for dimensional lumber 5"x5" and larger are different from those listed in Table 2.6, but these are not typically used as formwork components.

Table 2.6: Wet Service Factors, C_M (AWC, 2005)

F_b	F_t	F_v	$F_{c\perp}$	F_c	E and E_{min}
0.85*	1.0	0.97	0.67	0.8**	0.9
*when $(F_b)(C_F)$ is less than or equal to 1150 psi, $C_M = 1.0$ ** when $(F_C)(C_F)$ is less than or equal to 750 psi, $C_M = 1.0$					

Temperature Factor (C_t):

The temperature factor is to be used for formwork components used in both dry and wet conditions, only if the temperature at which the wood is being used is 100° F or above, for extended periods of time. Wood tends to lose strength at high temperatures and has a tendency to gain some strength as it cools down. The temperature factor values can be seen in Table 2.7.

Table 2.7: Temperature Factor, C_t (AWC, 2005)

Reference Design Values	**In-service moisture conditions**	**C_t**		
		T≤100°F	**100°F<T≤125°F**	**125°F<T≤150°F**
F_t, E, E_{min}	Wet or Dry	1.0	0.9	0.9
F_b, F_v, F_c, and $F_{c\perp}$	Dry	1.0	0.8	0.7
	Wet	1.0	0.7	0.5

Incising Factor (C_i):

The reference design values are multiplied by the incising factor when the dimensional lumber is incised parallel to grain a maximum depth of 0.4 inches, maximum length of 0.375 inches, and density of incisions up to 1100/ft^2. For members with incisions that conform to the mentioned specifications, the necessary reference design values should be multiplied by the appropriate incising factor C_i, as provided in Table 2.8.

Table 2.8: Incising Factors, C_i

Reference Design Values	**C_i**
E, E_{min}	0.95
F_b, F_t, F_c, F_v	0.80
$F_{c\perp}$	1.00

Incising factors are determined by testing or by calculation using reduced section properties for incisions with properties that exceed the aforementioned limits.

Beam Stability Factor (C_L):

The beam stability factor C_L accounts for the effect of lateral-torsional buckling in F_b, and is always equal to 1.0 if the depth of the bending member does not exceed its breadth, or if the depth of the member exceeds its breadth and the member is restrained against any kind of lateral displacement. For members that do not meet the aforementioned criteria, the value of C_L will be less than one, and can be calculated using the guidelines in the *National Design Specification for Wood Construction* (AWC, 2005).

Repetitive Member Factor (C_r):

Reference design values for allowable bending stress, for dimensional lumber 2" to 4" thick should be multiplied by a repetitive member factor $C_r = 1.15$, when they are used in contact with other load distributing elements which are able to support the lateral load, or if used at a spacing of not more than 24" on center. This 15% increase in F_b is based on the provisions set forth by ASTM D245 and ASTM D6555, and accounts for the increase in the capacity and stiffness when multiple framing members are fastened together by other transverse members.

Concrete Setting Factor (C_s):

The concrete setting factor is not specified or defined in either of the major references for formwork design - *Formwork for Concrete* (Hurd, 2005), or the *National Design Specification for Wood Construction* (2005). It is referred to in the *Concrete Forming- Design/Construction Guide* (APA, 2012). This factor is applicable to the tabulated bending and shear stress values of plywood, and is formulated so as to account for the ability of concrete to carry its own weight as it cures over time. A concrete setting factor of 1.625 is obtained as the product of the load duration factor (C_D) equal to 1.25 and an experience adjustment factor equal to 1.30. The experience factor is not mentioned either in the SP-4: Formwork for Concrete (Hurd, 2005) or the National Design Specification for Wood Construction (2005). No additional information was found by the research team regarding this adjustment factor.

After looking up the appropriate factors, the reference design values are obtained from tables either in the Formwork for Concrete (Hurd, 2005) or in the National Design Specification for Wood Construction (AWC, 2005), and the relevant factors are applied to the appropriate value, as shown in Table 2.9.

Table 2.9: ASD Factors used in formwork design (AWC, 2005)

	Load Duration Factor	Wet Service Factor	Tempe-rature Factor	Beam Stability Factor	Size Factor	Flat Use Factor	Repetitive Member Factor	Incising Factor
$F'_b=F_b$	C_D	C_M	C_t	C_L	C_F	C_{fu}	C_r	C_i
$F'_v=F_v$	C_D	C_M	C_t	--	--	--	--	C_i
$E'=E$	--	C_M	C_t	--	--	--	--	C_i

Table 2.9 only provides details about the factors relevant to design of formwork. For more comprehensive tabulated data, and further details regarding wood design, it is recommended that the National Design Specification for Wood Construction (AWC, 2005) be referred.

2.3. FORMWORK USE AND REUSE

Concrete formwork is re-used in projects to facilitate and economize the concrete construction process, as re-use can possibly reduce the costs associated with formwork, as well as provide for a more sustainable solution. It is worth noting that there is limited availability of literature that provides guidance on how to quantitatively assess factors that have direct impact on the re-use of formwork, as well as the fact that none of the adjustment factors discussed in Section 2.2 are related to formwork re-use. Most literature, related to formwork use, either describe engineering judgment as the main decision criterion used for determining whether a piece of formwork can be used again or not (Hurd, 2005), or provides general guidelines such as *Formwork Design* (Ringwald, 1985) for use of formwork. Formwork use guidelines consist of general industry practices, and is considered common knowledge, as imparted by *Formwork for*

Concrete (Hurd, 2005) and works based on the aforementioned guide by Ringwald (Formwork Design, 1985).

A relatively newer study conducted in Singapore describes various factors that contribute to the re-use of traditional timber formwork (Ling & Leo, 2000), and identifies five main factors that affect the re-use of traditional timber formwork. These five main factors are:

i. Materials used to fabricate the formwork;
ii. Workmen who work with the formwork;
iii. Design of the completed structure;
iv. Design, fabrication, and stripping of the formwork; and
v. Site management issues.

After examining the effects of fifteen sub-factors that fall under the main factors, Ling and Leo (2000) conclude that only three sub-factors have any impact on the reusability of formwork. These are: (i) the working attitudes of workers, (ii) the efficiency of the crew, and (iii) the formwork stripping or formwork striking process. Of these, all three sub-factors belong to the second main factor listed above - Workmen who work with formwork; hence, it can be concluded that the most important factor that affects formwork re-use is the workmen who handle formwork on-site.

To identify and assess factors that impact the reuse of formwork, it is also necessary to define the activities that constitute one use cycle of formwork. The typical use of traditional timber formwork on a project has been assumed to be common knowledge, and the use of formwork is implied to consist of assembling and erecting forms, setting rebar, pouring and curing concrete, and stripping the forms from the cured member (Hurd, 2005, pp. 10-1 to 10-25). The activities that a construction worker has to execute in due course of using concrete have been defined as (Hallowell & Gambatese, 2009):

i. Transport materials and equipment without motorized assistance;
ii. Transport materials using construction vehicle or other motorized assistance;
iii. Lift or lower materials, form components or equipment;
iv. Hold materials or components in place (static lift);
v. Accept/load/connect materials or forms from crane;

vi. Cut materials using skill or table saw;
vii. Nail/screw/drill form components or other materials;
viii. Hammer using sledgehammer or other equipment;
ix. Plumb and/or level forms using body weight, pry bar or other equipment;
x. Ascend or descend ladder;
xi. Work below grade or in confined space;
xii. Work above grade (>5 feet) or near uncontrolled opening;
xiii. Inspect forms and construction planning; and
xiv. Excavation.

It is to be noted that this list identifies all activities that may or may not be performed during formwork use and re-use, and are not in any particular chronological sequence.

2.4. RISK ASSESSMENT

An extensive literature review and search of online resources show that risk assessment pertaining to the risks associated with formwork use has been performed previously. There exists previously conducted research that assesses the risk associated with the fourteen activities involved in the use of formwork using the Delphi method (Hallowell & Gambatese, 2009). In the study, a panel of experts in the construction industry was asked to quantify the associated risks using probability, severity, and the exposure associated with each activity. Risk associated with each activity is calculated as follows (Hallowell & Gambatese, 2009; Jannadi & Almishari, 2003):

$$\text{Risk} = \text{Probability} \times \text{Severity} \times \text{Exposure}$$

where:

- Probability - Likelihood of occurrence of an incident;
- Severity - Potential outcome of the event; and
- Exposure - Time spent by the worker in contact with a potential hazard.

After the completion of the initial phase and definition of a sequential formwork cycle, it can be seen that the viewpoints of the project administrators are different from that of the field workers in several instances. Hence, an effort was made by the research team to carry out a similar risk assessment, but the target population was shifted to the construction personnel in the field, who work hands-on with formwork. Further exploration of this method can be found in Chapter 3.

There is additional literature available on different methods of risk assessment in construction as well as other fields of study. Two methods for addressing parameter uncertainty in risk assessment have been discussed by Guyonnet et al. (1999). A study from China (Longquan, Youliang, Liang, & Wu, 2011) on method selection for building safety risk assessment gives information about the application of different methods of risk assessment to building construction, of which two methods are Risk Matrix Analysis and Risk Factors Checklist. The authors state that risk assessment for buildings comprise of two major steps: identification of risks, and assessment of the possible impacts of the identified risks, i.e., risk levels. To do so, the safety status of buildings and risk factors are respectively categorized into four levels depending on the level of impact on building safety: (i) Grade A – Safe, (ii) Grade B – Generally safe, (iii) Grade C – Local unsafe, and (i) Grade D – Seriously unsafe. The main disadvantage of the risk methods employed that was identified was that the risk assessment remained qualitative due to lack of empirical data.

Risk models are often used to carry out quantitative cost and schedule risk analysis of construction projects (Grey, 1995). These models provide estimates that account for the uncertainty produced due to factors such as inflation, project environment, hazards, and labor issues. The estimates obtained provide a clearer picture of the actual schedule and cost, rather than an expected value. The estimate of risk calculated using equation (2.5) gives an expected value of risk. This expected or average value may not be a true assessment of risk. Hence, in the present study, a risk model is built using the @Risk software to analyze the calculated risk, and obtain a probability density of the risk values. @Risk software is a tool developed by Palisade Corporation as an add-in to Microsoft Excel. This software was chosen due to its easy availability, ability to merge seamlessly with Excel functions for basic statistical calculations, and the user-friendly interface. Additionally, sensitivity analysis, used to isolate key factors, or in this case, key inputs that significantly affect the output risk value (Smith, 1999), can be performed with relative ease using @Risk.

2.5. RELIABILITY ASSESSMENT OF TEMPORARY STRUCTURES

Reliability studies of structures are performed to assess a structure's ability to fulfill the structure's design purpose for the specified design life (Novak & Collins, 2013). Reliability can be said to be equivalent to the probability that the structure will not fail or underperform when put to the intended end use. Most design codes used in current practice are based on probabilistic models of loads and resistances

Reliability problems can be formulated to assess the probability of failure and reliability of structures, and in this case, the probability of failure and reliability of formwork. There are three levels of formulation of the basic problem, as put forth in *Structural Safety* (Borges & Castanheta, 1985)-

- Level 1 – Semi-Probabilistic: The safety parameters used are partial safety factors and/or tolerances affecting characteristic and design values. Probability computations are performed using design algorithms weakly related to probability of survival.
- Level 2 – Probabilistic Approximate: Probabilities of survival are substituted for by reliability indices corresponding to bounds of probability of survival. Approximate values of the probabilities of failure and survival are computed.
- Level 3 – Probabilistic Exact – Exact values of probabilities of failure or survival are computed using integrals that define the probabilities.

In this study, the Level 2 approach is adopted and the reliability indices and probability of failure is computed.

A review of other available literature shows that investigations have been conducted previously to investigate the causes of temporary structure failure. Causes of failure of temporary structures have been identified (Hadipriono & Wang, 1986), and further evaluated using Event Tree Analysis (Hadipriono, Lim, & Wong, 1986). In the former study identifying and categorizing causes of failure of temporary structures, concrete formwork was identified as the fourth category out of 5 categories of falsework, and 13% of the cases out of 85 total cases investigated in the study were found to be related to this category (Hadipriono & Wang, 1986).

In the second related study, an event tree analysis was performed on a typical bridge formwork and falsework system, and a procedure to evaluate the probability of failure, which gives the most likely path of failure was developed (Hadipriono, Lim, & Wong, 1986). According to the authors, the aforementioned procedure could be applied to any structure to predict potential failures, and to establish quality control to reduce causes of failure.

CHAPTER 3. METHODOLOGY

3.1. INTRODUCTION

In this study, there are three primary objectives (PO) and five secondary objectives (SO). The PO are established to expand the general understanding of formwork use, as well as the associated risk and reliability in formwork use and re-use. The PO established are:

PO # 1 - Map the typical use cycle of formwork on-site

PO # 2 - Identify the primary factors contributing to risks associated with the use and re-use of formwork and evaluate the risks posed to the workers caused by the execution of various activities that comprise the formwork cycle

PO # 3 - Evaluate the reliability associated with formwork use and re-use

The secondary objectives established in support of the PO are:

SO # 1 - Establish a sequence of activities that represent an overall formwork cycle

SO # 2 - Determine the main factors that impact formwork lifecycle on a project

SO # 3 - Identify the major causes of accidents related to formwork

SO # 4 - Quantify risk associated with each activity in the established formwork cycle

SO # 5 - Evaluate the change in strength characteristics of formwork between uses

Due to the nature of the SOs established, it is necessary to carry out research using multiple methods. The relationship between the different objectives and associated research methods is represented in Figure 3.1.

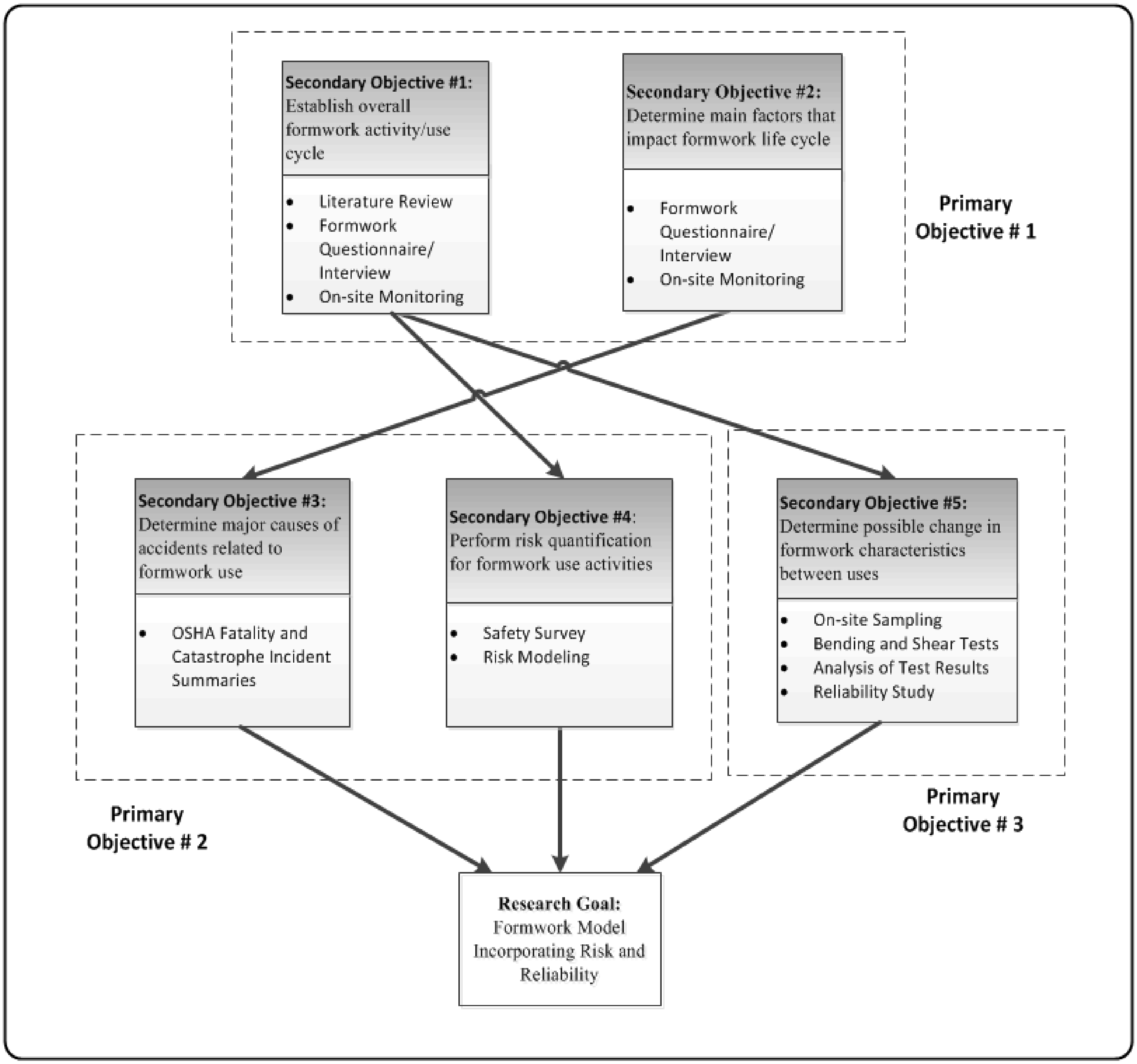


Figure 3.1: Research Scheme

To meet SO #1 and SO # 2, a combination of observation, interview and survey methods of research was deemed the most suitable. Initially, on-site interviews were carried out in order to obtain and establish the standard procedures of formwork use, and determine factors impacting the formwork lifecycle. Based on these results, on-site monitoring of formwork was carried out and a sequence of activities representing the workflow of a general formwork use cycle was obtained. Further, based on this general mapped workflow, project specific mapped workflows can be established.

OSHA Fatality and Catastrophe Investigation Summaries (OSHA, 2013) are used to identify the main causes of accidents related to formwork, i.e., SO #3. SO #4 is met by obtaining formwork samples from chosen projects with concrete work which is an experimental research method, and the final SO #5 is met using a Safety Survey. Further details of these methods are discussed in this chapter.

3.2. FORMWORK MONITORING

As the first step in identifying factors that impact the lifecycle of formwork, two methods of formwork monitoring were considered: (i) a formwork questionnaire, to be answered in an interview format, and (ii) on-site tracking of formwork, which was to be conducted after identifying the most important criteria considered by construction personnel pertaining to re-use.

3.2.1. FORMWORK QUESTIONNAIRE

To identify the various activities associated with the formwork cycle in detail, a questionnaire was developed and used for conducting interviews of formwork construction personnel. The purpose of the questionnaire was to obtain information and record observations pertaining to formwork activities and formwork use, as well as to identify the criteria used to determine the re-usability of formwork components in real-time projects. This was regarded as a preliminary attempt at obtaining the various stages of use in the formwork cycle. The questionnaire was divided into eight sections.

The first section of the formwork questionnaire aimed at collecting general information about formwork components at the project site, the ownership of the formwork, formwork design considerations other than those prescribed in ASCE 37-02, and frequent issues associated with vertical formwork use. In addition, the first section was designed to identify decision processes on how formwork condition is assessed on the project leading to formwork components and panel reuse.

The second section solicited information related to storage and stockpiling of formwork, and various factors that may have some impact on the storage of formwork.

The third section of the questionnaire asked about the assembly steps of vertical formwork, differences in the assembly and erection of column and wall formwork, and the connections typically used on projects.

The fourth section dealt with the placement and curing of concrete, and gathered information regarding the duration of wait time of formwork before, during and after concrete pours, as well as any possible seasonal variations in the durations.

The fifth section collected information on the transportation and removal of formwork, both within projects and from one project to another. This section is used to characterize the impact of formwork transportation activities on its use and reuse.

The sixth section of the questionnaire asks open ended questions concerning the most common types of degradation found on formwork, and the number of uses after which each type of degradation is typically observed. Additionally, this section also asks about the methods used for assessing whether a particular section of formwork can be used again or not, and if there are any manufacturers' instructions regarding the number of re-uses.

The seventh section collects information about the causes of formwork failures typically observed, and the injuries associated with formwork on the project. This section allowed respondents to specify typical causes of formwork failure, as well as types and magnitudes of injury on the project.

The eighth and final section of the questionnaire was added in to identify the importance that various factors have on the number of uses of formwork and/or the various formwork components. A table showing various factors that impact the formwork was provided with the provision for respondents to add other factor(s) considered important. The respondent was asked to rate the impact of each factor in the table on a scale of 0 to 5, ranging from no impact (0) to a very large impact (5).

It is worth noting that in the questionnaire, certain questions are project specific, while most questions were applicable to every project. Most questions were presented in a multiple-choice format, with the option of checking all applicable options. Additionally, space was provided after each question for the respondent to put down any other answer of their choice. The questionnaire can be seen in Appendix I.

The targeted population for this questionnaire was those personnel identified as having obtained extensive knowledge of formwork use, and who were working at a construction project at the time of interview. After identifying the target population for the questionnaire, approval for conducting the interviews was sought and obtained from the OSU Institutional Review Board (IRB) with the necessary documentation. The IRB ruled that the study was not Human Subject Research. Multiple personnel were interviewed from various projects, depending on their willingness and availability. Initially, queries were sent to contact persons at 15 prominent construction firms located in Northwest Oregon enquiring about the availability of any ongoing projects involving concrete formwork, and the possible availability of workers to respond to the questionnaire. The selected contact persons were graduates of the Civil and Construction Engineering Department known to be working in the construction industry. Permission was requested using the same email to interview relevant personnel on the project, as well as to conduct a project walk-through to understand how formwork is used, handled and stored in the particular project. Appointments were fixed with the right contact at the project site, and interviews were conducted, followed by a site walk-through.

3.2.2. ON-SITE MONITORING

Three projects were identified within close proximity of the Oregon State University campus. The main selection criteria was that all these projects made use of traditional timber vertical formwork. The projects were all in the same region so as to maintain constant accessibility by the research team to the project site throughout the duration of the concrete construction activities. The research team gained access to the project site, regularly observed the movement and use of formwork, and maintained photographic records of many formwork use cycles that occurred during the project. Any potential safety issues and additional impacts to formwork were noted.

To reduce variability by maintaining consistency in loading patterns and general use conditions, observations were limited to vertical formwork at every project site. For the purpose of this study, vertical formwork includes wall, column, and foundation formwork.

3.3. MAPPED WORKFLOW

Information gathered from on-site observations and from the questionnaire was used to generate two types of formwork mapped workflows. First, a mapped workflow for one cycle of general formwork use, which is applicable to any construction site, was developed and second, project specific mapped workflows for the formwork use observed in the three monitored projects were developed.

The mapped workflow for general formwork use is representative of one complete formwork use cycle containing all possible steps that could be involved in formwork use, and is generally applicable to any project site. The actual formwork use cycle that occurs at any project site would be comprised of at least some of the steps that are defined in the workflow. In some projects, some of the activities in the formwork cycle can be skipped or performed concurrently, depending on the project conditions. For example, the stockpiling stage after stripping can be skipped and the formwork can be directly erected for the next pour or assembly and erection activities may take place at the point of use simultaneously. In case some activity is skipped, the time/cost/waste associated with that activity would be set to zero and thus the flow would not account for that activity, making this a general model.

The project specific mapped workflows show all possible formwork activities that were executed on site during the course of the project. Project specific workflows were developed to aid in the definition and validation of the mapped workflow of general formwork use. It is worth noting that the activities that constituted each project specific formwork cycle were governed by many factors such as the space available on the construction site, weather, schedule, required concrete surface finish etc.

3.4. CAUSES OF ACCIDENTS RELATED TO FORMWORK

3.4.1. OSHA CASE STUDIES

To gain some historical perspective into causes of accidents related to formwork, the research team went to the most readily available and continuously updated source of recordable incidents, which is the incident database maintained by the Occupational Safety and Health Administration (OSHA) This database is known as the Fatality and Catastrophe Investigation Summaries (OSHA, 2013). A search of this database revealed that there were 438 cases recorded incidents associated with the keyword “concrete form work” out of 22902 incidents associated with construction (2%), dating from the year 1984 to the year 2012. All of the cases found associated with concrete formwork were summarized and grouped by the research team according to two different criteria: (i) severity of injury, and (ii) formwork activity being performed at the time of incident. The summary of incidents obtained as a result is attached in Appendix-II.

OSHA CFR 1904 states that criteria used to make the decision of whether a work-related injury or illness is recordable is if it results in one or more of the following- loss of consciousness, medical treatment beyond first aid, more than one day away from work, restricted work or transfer to another job, significant injury or illness diagnosed by a physician or other licensed health care professional, or death (CFR, 2001). The severity of incidents has been classified into four different levels by Dharmapalan (2011). The four severity levels set forth by Dharmapalan (2011) are:

i. Near Miss: No impact on work time, no or negligible injuries sustained, assigned a value of 1
ii. Low Severity: Temporary and/or persistent discomfort and pain, requiring minor first aid, assigned a value of 17
iii. Medium Severity: Required major first aid or medical attention, loses more than one work day, assigned a value of 158
iv. High Severity: Incident resulted in death or permanent disability, worker could not return to work in the same capacity, assigned a value of 14,282

The incidents were also classified according to the activity that was being performed when the incident occurred. The research team categorized the incidents based on activities that constitute the mapped workflow of the general formwork cycle. The main categories based on activities were “Transportation”, “Stripping”, “Erection”, “Assembly”, “Forming”, and “Pouring Concrete”. In cases where the activity performed by the injured worker was known, but unrelated to formwork use in any way, assignment was made to the category of “Other”. If the activity being undertaken was not specified in the investigation summary, the incident was assigned to the category “Not specified”.

This categorization provides valuable insight into the main causes of incidents related to formwork as well as the activities that have resulted in the maximum amount of incidents. Further, the categorization can assist in the risk assessment related to each activity in the formwork cycle.

3.5. SAFETY RISK SURVEY

To assess the risk associated with the each activity in the formwork cycle, a Safety Risk Survey was developed. In this survey, participants were asked to rate the probability of occurrence of an incident of each of the four severity levels using a pre-defined frequency scale. In addition, participants were also asked to indicate the time spent working on each activity as a percent of the total time spent working on formwork to quantify exposure. The survey is listed in Appendix III-A.

For this survey, the participants targeted were workers who have hands-on experience in the use of formwork, and hence are exposed to the various safety risks and hazards associated with formwork usage. Possible respondents were approached in two ways; first, by going to project sites with concrete construction and obtaining permission from the Project Engineer/ Foreman to obtain survey responses, and second, by attending the Pacific Northwest Regional Council of Carpenters (PNRCC) meetings and having the attendees fill out surveys. Responses were gathered from four different gatherings. Two gatherings consisted of groups of workers at two project sites organized specifically to obtain survey responses, and the other two were monthly PNRCC meetings. The participants were provided with initial information about the research study, and also about the severity levels of incidents and the frequency ratings. The frequency ratings adopted are described in Table 3.1 (Dharmapalan, 2011) :

Table 3.1: Frequency Ratings

Frequency Scale Value	**Original Range**	**Worker Hours/ incident**	**Incidents/ worker hour**
10	1 hour	1	1.000000
9	1 day	9	0.111111
8	1 week	45	0.022222

Frequency Scale Value	Original Range	Worker Hours/ incident	Incidents/ worker hour
7	1 month	189	0.005291
6	6 months	1134	0.000882
5	1 year	2250	0.000444
4	5 years	11250	0.000089
3	10 years	22500	0.000044
2	50 years	112500	0.000009
1,0	Negligible	0	0

The rounded mean/median frequency value and activity exposure value are calculated from all the responses received, and the risk value for each activity is calculated. The risk for each activity is calculated from the rounded mean/median frequency values for severity using the following equations:

$$\text{Total Unit Risk} = \sum (\text{Frequency x Severity}) \quad (3.1)$$

$$\text{Cumulative Risk} = \sum (\text{Exposure x Frequency x Severity}) \quad (3.2)$$

The terms used in equations (3.1) and (3.2) as defined in Chapter 2.

The responses obtained from the survey are tabulated, and an appropriate probability distribution function (PDF) is assigned to each severity level. The PDF used is selected after the examination of histograms of the responses obtained for each category, at each severity level. The selected PDF for each activity is assigned, tabulated, and a model created using the software @Risk. The software can run a specified number of iterations, and provide the probability density curves for the unit risk and cumulative risk associated with an entire formwork use cycle. The model can be set up to run any number of cycles. In this study, the model was created to provide the risk for a single cycle, with the assumption of no deterioration in properties.

3.5.1. JUDGEMENT BASED BIASES

Bias can be defined as any factor or effect that distorts the true nature of an opinion or observation, and can lead to inaccurate results and conclusions (Hallowell M. , 2008). There is a possibility of judgment based bias occurring in the responses obtained, affecting the safety risk survey responses and consequently, the risk model output. Since the respondents would be providing responses to the safety survey based on their opinion of perceived risk and judgment based on their experience of handling and using formwork, an effort was made to mitigate and remove biases. Different possible judgment based biases (Hallowell M. , 2008) applicable to the survey, and methods to minimize these biases, are discussed in this section.

Collective Unconscious:

The theory of collective unconscious or the “bandwagon effect” states that the respondents tend to join a popular trend. Individuals may feel compelled to match their opinion to the standard beliefs existing in a particular group. This is a possibility if multiple responses are obtained from one construction project due to the safety culture of the organization. This possibility was reduced by collecting information from PNRCC meetings, which are attended by workers belonging to many different organizations, as well as by emphasizing that the survey is based on the individual opinion of the worker, and not project-specific.

Neglect of Probability:

Workers may underestimate the role of probability and assign lower frequency scale ratings, due to reduced risk perception. In the survey, since the frequency values are used only to determine the activities that post the largest amount of risk in one formwork use cycle, the actual numbers do not affect the outcome of the safety survey and risk model. For example, Worker A may provide a rating of 10 for a Near miss incident and in a similar trend, 5 for a High severity incident, whereas Worker B may start with a rating of 6 for a Near miss incident during the same activity, subsequently providing a rating of 1 for a High severity incident. Although the rating values may start at lower values, they will still follow the same trend, i.e., Near miss incidents will have the highest rating, followed by Low severity, Medium severity and High severity incidents respectively. The risk model obtained depends on the trend mentioned above rather than the exact numerical values. This bias would need to be accounted for further if the risk model is modified to incorporate increased risk due to deterioration as the number of uses increases, and if the total risk values thus obtained are compared to the total risk values when no deterioration in factored into the model.

Von Restroff Effect:

According to the Von Restroff Effect, subjects are found to recall incidents of high severity more accurately than less extreme events, distorting a sense of probability. This bias was controlled and minimized by choosing workers at random construction projects or PNRCC meetings.

Recency Effect:

Workers are more likely to remember incidents that have occurred recently and accordingly inflate the probability of risk. For example, a person who has incurred a low severity injury recently will provide higher frequency ratings for that category compared to a person who has not incurred any injuries in the recent past. In this study, recency effect is minimized by obtaining thirty or more completed responses to the survey.

3.6. FORMWORK SAMPLING AND LABORATORY TESTING METHODOLOGIES

3.6.1. SAMPLE COLLECTION

To measure the possible deterioration in the structural capacity of formwork, and thus, assess the reliability of the same, formwork samples were collected from the three projects monitored. To compare the strength between each use, efforts were made to obtain samples of formwork which had undergone different number of uses. Each number of use would be considered one treatment. An unused sample was also collected from each project so as to have a basis of comparison to the used samples. For this study, samples of only the plywood sheathing were collected, rather than an entire form panel. This was done so as to maintain constant test sample dimensions and also to ensure that the same number of identical test specimens were tested from each treatment.

The samples were collected from sites both in the form of uncut 4’ by 8’ panels, and in some cases, smaller pieces cut on-site by workers for easier transportation, or depending on availability. The samples were transported into the testing lab and stored in a temperature and humidity controlled environment so that all specimens could be ultimately tested in the same moisture conditions. The size of test specimen depended on the test chosen, the end result required from the test, and the size and quantity of sample initially obtained from the project site.

3.6.2. TESTS PERFORMED

Concrete formwork is typically designed considering three design criteria of each form component- bending, deflection, and rolling shear (Hurd, Formwork for Concrete (SP4), Seventh Edition, 2005). The tests for plywood samples were selected based on two of the three criteria- bending and rolling shear.

To assess the possible change in bending capacity between different numbers of uses, Method B: Two-point Flexure Test of ASTM D3043 was chosen. Method B, otherwise referred to as third point bending test was chosen for testing the samples to obtain the bending capacity, provided that the specimen length is controlled.

To assess the possible change in rolling shear capacity between different numbers of uses, Method B prescribed in ASTM D2718 - Standard Test Methods for Structural Panels in Planar Shear (Rolling Shear) was used. Method B: Planar shear induced by five-point bending was chosen given that in this research, the specimen size is dictated largely by the availability of sample panels, and the loading of vertical formwork is perpendicular to the face of the plywood sheathing.

Prior to any test, the panels or the specimens were stored in a controlled environment under the conditions recommended by the ASTM standards, namely relative humidity of 65% ± 2% at a temperature of 68°F ± 6°F (20°C ± 3°C) so that the specimens can be brought to equilibrium moisture content during the tests, and are tested under uniform moisture conditions.

In addition to the test results, the moisture content of the specimens is also determined as per ASTM D4442 - Test Methods for Direct Moisture Content Measurement of Wood and Wood-Base Materials. Method A of this standard was the method selected. Method A is the Primary Oven Drying method and was used as there were no special circumstances or purposes that rendered Method A undesirable. In this test, moisture content of a specimen is determined by recording the initial weight, W_i of the specimen and then drying the sample in a drying chamber maintaining a temperature of 103°C ± 2°C for a period of twenty-four to forty-eight hours. The samples are then removed from the oven and weighed again to obtain the dry weight (W_d). The moisture content is calculated as a percent of the dry weight using the following equation:

$$\text{Moisture Content, \%} = (W_i - W_d)/ W_d \times 100 \qquad (3.3)$$

3.6.3. TEST SPECIMEN PREPARATION AND DIMENSIONS

The preparation of samples for the third point and five point bending tests, samples included cutting the samples using a panel saw or a table saw into specimens of appropriate size, which were then stored in a controlled environment under the conditions recommended by the ASTM standards. Uniform moisture content was deemed necessary to avoid possible variation in tested specimen strength due to varying moisture content. The same number of specimens were tested for bending or shear from each project and number of uses.

For determining appropriate test specimen size for the third point bending test, ASTM 3043 recommends that the span be 48 times the specimen thickness, plus the spacing between the two load points when the principal direction is parallel to the test span, or 24 times the specimen thickness plus the spacing between the two load points when the principal direction is perpendicular to the test span. The span can be reduced from this recommended value if the material has high rolling shear capacity, or if all plies are parallel to span. The span values mentioned do not include the overhang of an inch required on each side. The width of sample has no effect on the test, as long as it is greater than 2 inches for samples with thickness greater than 0.75 inches. The nominal specimen dimensions for the bending tests are as provided in Table 3.2. For calculations, the actual width and thickness of each specimen is measured close to load points.

Table 3.2: Nominal Specimen dimensions for Third Point Bending Tests

Project #	**Span (in)**	**Width (in)**	**Thickness (in)**
Project 1	26	4.5	0.75
Project 3	22	2.25	0.75

For the five point bending tests, ASTM 2718 recommends that the span shall be 16 times the nominal specimen depth when the principal direction is parallel to test span, and 11 times the nominal specimen depth when the principal direction is perpendicular to the test span. However, ASTM 2718 also says that the percent of shear failures will increase if the test span is reduced from the recommended value, and that the test span may be adjusted as long as all specimens have the same test span. An extra inch on each side is required as overhang, similar to the third point bending samples. The recommended range of widths of the specimens are 4.5 inches to 10 inches. However, this value may be adjusted for practical purposes. Based on these guidelines, and based on best use of the collected samples, the nominal specimen dimensions for five-point bending tests are provided in Table 3.3.

Table 3.3: Nominal Specimen Dimensions for 5 Point Bending Tests

Project #	**Span (in)**	**Width (in)**	**Thickness (in)**
Project 1	12	4.5	0.75
Project 3	10	2.25	0.75

It is to be noted that no specimens were prepared or tested from samples obtained from Project 2, as the number of uses the samples had undergone were unknown to the workers. Other formwork used on the project was rented, and was unavailable for sampling.

3.6.4. TEST SETUP

This section provides a brief overview of the test set up for the third point and five point bending test set up. Both tests were carried out using an Instron Universal Testing Machine. The load cell used is a 100 kN load cell, and the loading rates for each test were calculated from ASTM 3043 and 2718, and the calculated rates adjusted in such a way that each test finished approximately in 2 to 3 minutes. The test set up for the third point bending tests can be seen in Figure 3.2.

Figure 3.2: Setup for third point bending tests

The test span is divided into equal thirds, and load is applied from the top two points, henceforth referred to as load points. The end supports can rotate in order to accommodate irregularities in the specimen.

The test setup for rolling shear assessment using five point bending can be seen in Figure 3.3. In this setup, the sample span is divided into four equal lengths, and five load points; three support points below the sample, and two load points above the sample. The samples were all tested to failure. The actuator displacement and corresponding load are recorded, and the maximum load is reported as the test result.

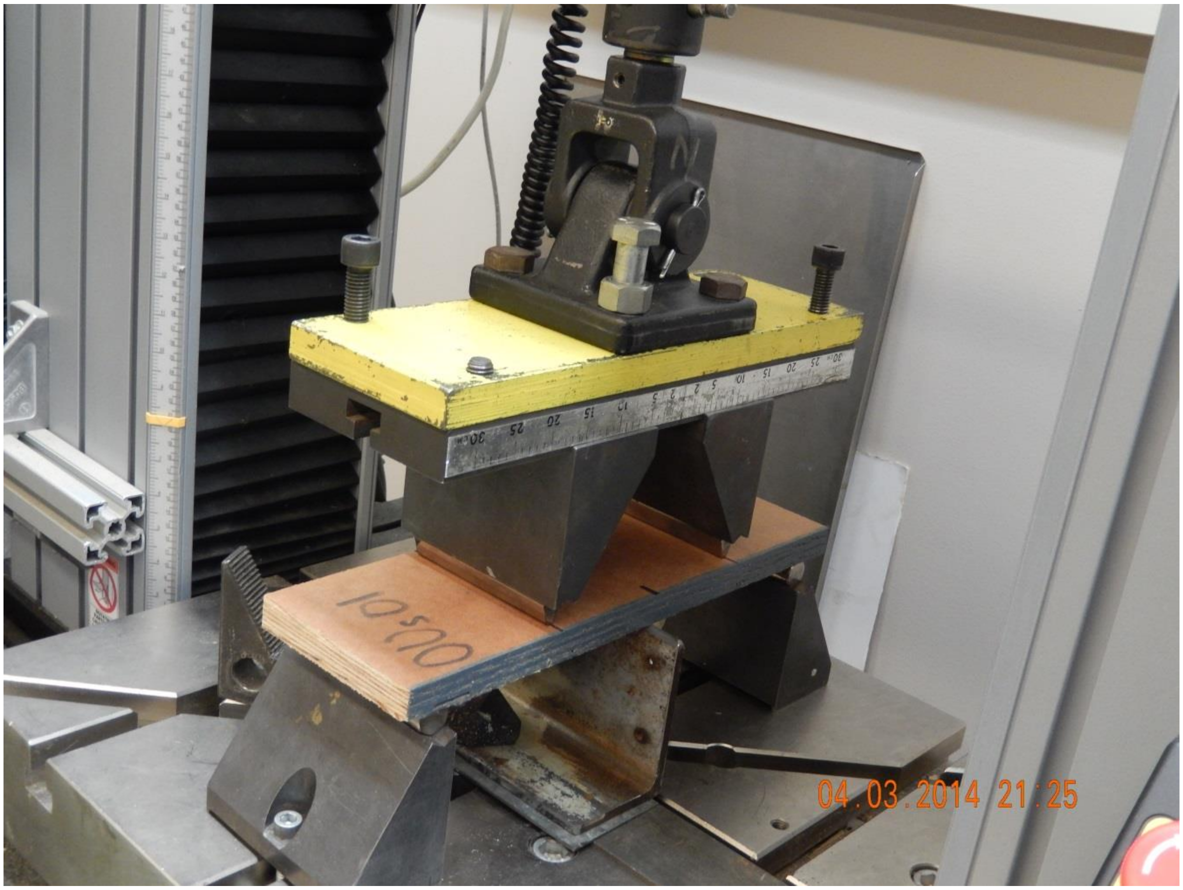


Figure 3.3: Setup for five point bending test

3.7. RELIABILITY ASSESSMENT

To understand and quantify the structural safety associated with formwork use, the reliability index, which is a safety index formulation, is employed (Novak & Collins, 2013). For the calculation of a reliability index, the resistance (or the moment carrying capacity), R, and the applied load (or the demand) Q, are required. Here, the capacity R is determined from the test data obtained from various uses as discussed in Section 3.6, while the demand Q is obtained from the design guidelines set forth in *Formwork for Concrete*. It is assumed that R and Q are normally distributed random variables, and that these are statistically independent. The standard deviation and mean of the capacity R are calculated from the various test specimens, while the variation in the demand Q is calculated using the standard deviation and mean of the concrete unit weight, obtained from literature (Ellingwood, Gambolos, MacGregor, & Cornell, 1980). The reliability index is calculated according to the following equation (Novak & Collins, 2013)-

$$\text{Reliability Index, } \beta = \frac{\mu_R - \mu_Q}{\sqrt{\sigma_R^2 + \sigma_Q^2}} \qquad (3.4)$$

Where μ_R = mean of capacity, R

μ_Q = mean of demand, Q

σ_R = standard deviation of capacity, R, and

σ_Q = standard deviation of capacity, Q

The reliability index is related to the probability of failure as follows, where P_f is probability of failure, and φ denotes a cumulative distribution function (CDF) -

$$\beta = -\varphi^{-1}(P_f), \text{ or } P_f = \varphi(-\beta) \qquad (3.5)$$

Thus, it can be seen that the higher the value of the reliability index, the lower is the probability of failure.

CHAPTER 4. FORMWORK MONITORING AND TESTING

This chapter discusses the outcomes of the various methods/approaches put forward by the research team to address the main objectives of this study, the mapped workflows obtained from the onsite monitoring and survey results, the results of the testing conducted and a discussion of the testing results. The formwork questionnaire was used to create a general formwork use cycle, with various activities laid out in sequence, as well as to obtain a general impression of the use conditions of formwork. In the next step, the use of vertical formwork was monitored and formwork use cycles were formed for each project. The mapped workflow for a general formwork use cycle is validated using the observed formwork use cycles in each project. To assess the common causes of accidents related to formwork, all 438 cases associated with formwork available at OSHA Fatality and Catastrophe Investigation Summaries were categorized according to severity and formwork activity. Formwork component samples of varying number of uses as well as design information for the relevant formwork were obtained from each of the projects, and these samples were tested in the laboratory to check for possible deterioration in strength with increasing number of uses.

4.1. FORMWORK QUESTIONNAIRE SUMMARY

Responses to the formwork questionnaire were collected from 20 construction industry professionals working in projects that involve the use of formwork. All 20 respondents belonged to eleven different construction projects located in Oregon. The distribution of the number of respondents from each project can be seen in Figure 4.1. The projects are numbered in chronological order of responses, and the number of respondents is indicated in the Y-axis. The respondents belonged to the posts of project manager, project engineer, superintendent and senior carpenter. At the beginning of the survey, the respondent’s name, project that they are currently working on, and the name of the company that they work for were collected as identifiers. It can be seen that there were 8 respondents from Project # 1, and these respondents included the Project Manager, Project Engineer, Foreman, Superintendent as well as a few carpenters.

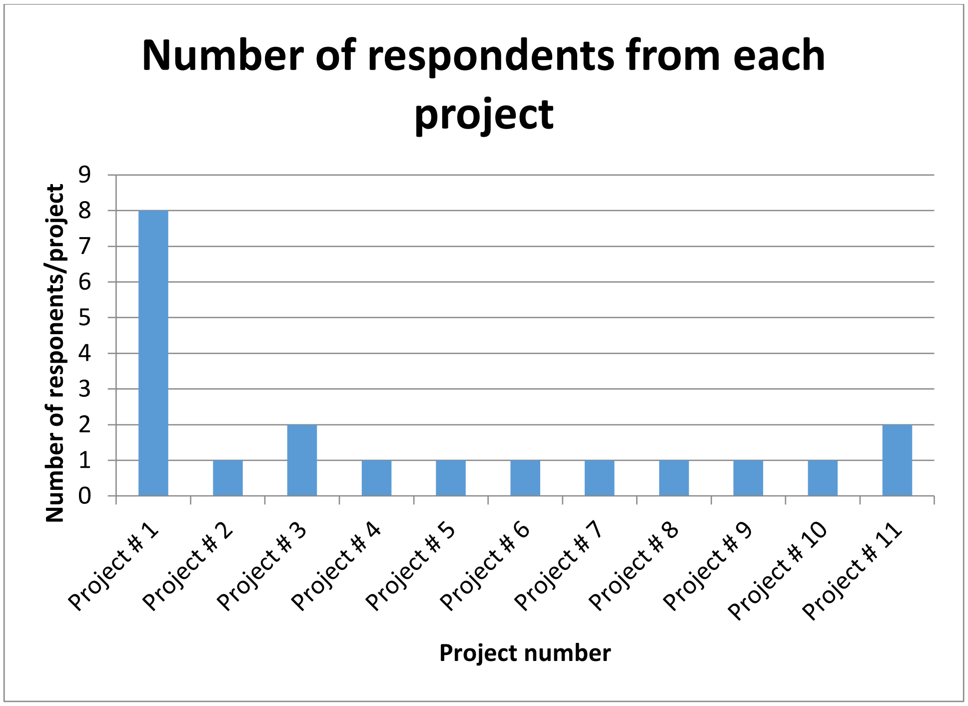


Figure 4.1: Number of respondents/project

The formwork questionnaire (Appendix I-A) is divided into eight sections. The first general section asks about the different components that are combined to build traditional handset formwork. The major formwork components identified were Medium Density Overlay (MDO) plywood, dimensional lumber, steel stakes, ties (either snap ties or taper ties) and hardware such as brackets, clamps, bolts, nails, etc. It could be seen that most projects that had a good amount of concrete formwork used a combination of handset or hand-built forms, and manufactured formwork systems such as Aluma System gang forms or Alisply Formwork Systems, both of which were assembled at the project site. These manufactured systems are typically rented, and consist of steel or aluminum studs, joists, and/or strongbacks with plywood faces. Formwork panels of desired dimensions are formed by putting together several smaller panels, and connecting them together using metal clamps or brackets. This practice makes the preparation, assembly and stripping of panels easier and more convenient compared to handset forms. To answer the question of loads considered other than design loads, 10 respondents (50%) chose the option of manufacturer's specifications, 10 respondents (50%) chose the option of worker load, and 8 respondents (40%) chose the option of embedments. Other possible responses for loading were rain and snow loads, but the majority did not choose these options. The major problems associated with vertical formwork use were recognized to be surface finish by 17 respondents (85%) and formwork being out-of-plumb By 13 respondents (65%). Nineteen respondents (95%) said that used formwork could be used again in the project, provided that it is in good condition and the condition of formwork components is assessed by looking for warping, cracks, straight edges, and uneven surfaces by visual inspection.

The second section enquired about the storage of formwork. It was found that for the most part, formwork was stored outdoors in 85% of the cases (17 responses), exposed, and on platforms called dunnage by 14 respondents (70%). Major factors that influence the storage of formwork were found to be size of jobsite, quantity and type of formwork, and duration of storage. Most interviewees felt that formwork storage may influence formwork performance in the long-term, but not for short durations during a project. Storage of forms in flat, covered stacks sorted and banded according to dimension would prevent warping and distortion, as well as facilitate efficient re-use at a later point in time.

The third section enquired about the assembly process. All interviewees, in essence, described the same process for the erection of formwork. The main steps were establishing gridlines, cutting formwork components to size, assembling formwork panels, and fixing them at the place of use, either by hand or using a crane/forklift. The major differences between the erection process of wall formwork and column formwork were found to be the connections holding the panels together: wall formwork typically uses taper ties, which can be pulled out after the forms are stripped, or snap ties, the ends of which are broken off after stripping of the forms. For column forms, the panels are held together using brackets or banding around the forms.

The fourth and fifth sections contained questions regarding the time frames for the process of concrete placement in the forms, and transportation and removal of formwork respectively. It was found that most vertical forms are stripped on the day after pouring, as long as the weather permits. Weather conditions such as snow or extreme cold/rain would cause the forms to stay on longer so as to enable proper curing of concrete as well as to prevent any damage to the concrete members. The majority also answered that formwork is moved within the project site by forklifts, crane or by hand, while it is transported from project to project in trucks or in one case, by barges. For the stripping of formwork from concrete, 19 respondents (95%)

indicated removal by hand, while 14 respondents noted removal by mechanical means such as cranes, forklifts, or hydraulic jacks.

The sixth section enquired about observed degradation in formwork. While 17 respondents (85%) felt that degradation of edges and corners were observed and 15 respondents (75%) felt that the formwork faces exhibited degradation, only 8 respondents (40%) felt that any structural cracking or degradation was observed. Shrinkage, and warping were also mentioned additionally as degradation of formwork. Out of 20 respondents, 19 (95%) said that all degradation was assessed only visually, and the judgment for this visual assessment comes only from experience. Only six respondents (30%) were aware of any manufacturer's guidelines for extended use, and most said that these were not taken into account.

The seventh section addressed any possible injuries or near misses associated with or formwork failures at the project site. Only two respondents (10%) reported an injury associated with formwork, or formwork failure, while 6 respondents (30%) mentioned low severity injuries on the job. Upon being asked to identify typical causes of formwork failure, 14 respondents (70%) chose the option of blowouts, while 12 respondents (60%) chose failure of connections or ties. The typical criteria for which formwork is designed – bending, deflection and shear – were not found to be typical causes of failure by the majority of the respondents.

The eighth and final section of the survey contained an impact table, which required the respondents to rank various factors that the research team had deemed to likely impact the lifecycle of formwork on a scale of 0 to 5 of increasing importance. The factors rated the highest by most respondents were removal of formwork, warping, connections and ties, surface damage and assembly. A brief summary of the questionnaire results can be found in Appendix I-B.

4.2. FORMWORK MONITORING

Three projects were selected and monitored by taking photographs and noting various activities during the use of formwork to validate the mapped workflow of general formwork use cycle, as well as identify any possible extra loads to formwork that are typically not considered during the design process but may have a considerable impact. The projects monitored are referred to as Project 1, Project 2, and Project 3 based on chronological order. Project 1 comprised of the construction of a four story building with concrete shear walls and columns.

The construction of a building with a concrete basement was monitored in Project 2. The rest of the building was constructed out of steel. Project 3 involved the construction of a four story mixed use building, with the first floor made of concrete, and the remaining floors constructed using wood.

Since all three projects monitored had different types of formwork, the use of all the different types was observed. A sample of the photographs obtained showing the different types of formwork can be seen in this section.

Figure 4.2, Figure 4.3, and Figure 4.4 show the different types of formwork used in Project 1. Figure 4.2 shows the erection of a shear wall form in progress. First, one side of formwork was installed, and then the workers tie off their fall protection systems into the wall form to fix the braces to the form, while two other workers place the other side of the form, which is held up by a crane (not visible in Figure 4.2). The wooden portion visible is the bulkhead, used to form the end of the shear wall.

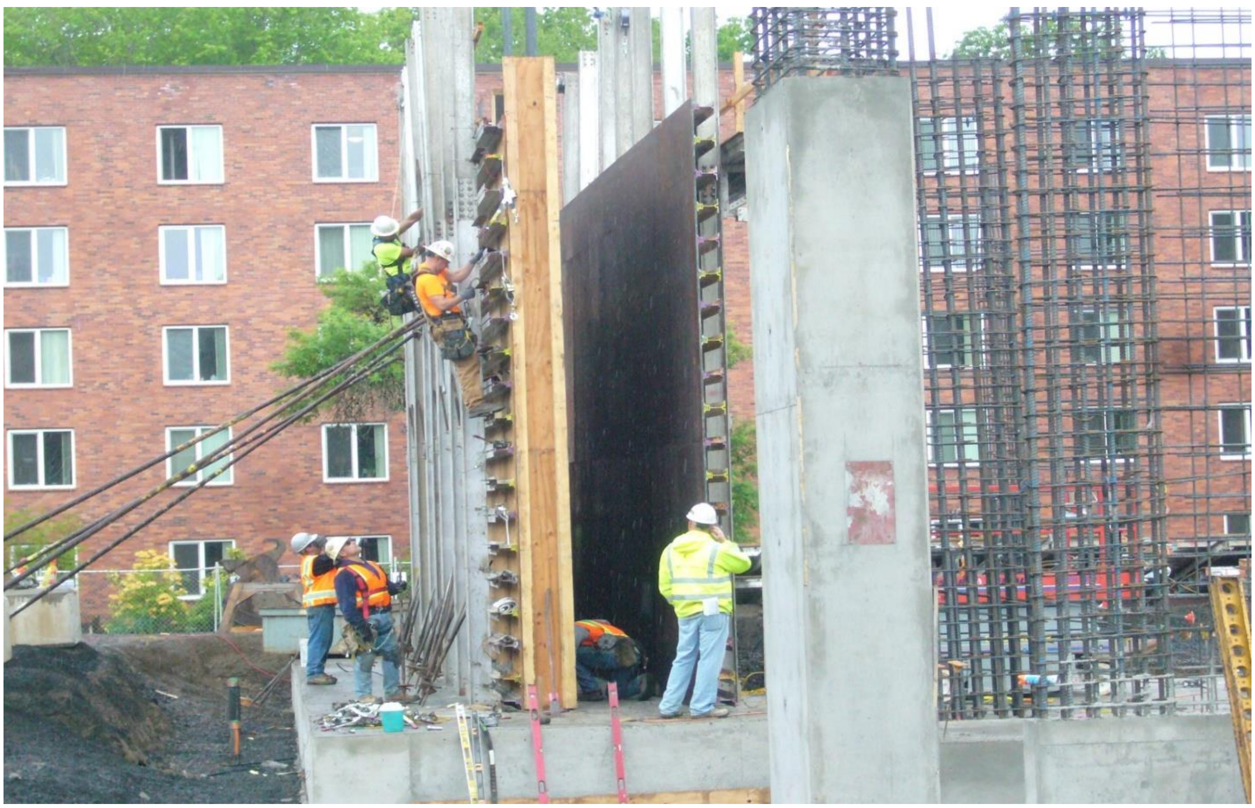


Figure 4.2: Wall forms being Erected, Project 1

Figure 4.3: Erected column form, Project 1

Figure 4.4: Base wall formwork ready to be stripped, Project 1

Column formwork used in Project 1 can be viewed in Figure 4.3. Figure 4.4 shows formwork for a base wall, which is to be covered later by fill. The base wall formwork is similar to the foundation formwork used in this project. The walls and columns were to have the concrete surfaces exposed to view after completion, and hence, the forms used were of better quality compared to the form shown in Figure 4.4. The foundation formwork panels used in Project 1 were used in previous projects. The exact number of previous uses was unknown.

The different formwork systems used in project 2 can be seen in Figure 4.5, Figure 4.6 and Figure 4.7. In Figure 4.5, the wall forms, made of Alisply Formwork systems, have been partially erected. The other side of the wall formwork was placed after all reinforcing steel was arranged satisfactorily.

Figure 4.5: Wall formwork systems partially erected, Project 2

Figure 4.6: Preparation of formwork components, Project 2

Figure 4.6 above shows strip footing foundation formwork (top left corner) in the background. Rather than using plywood, 2x12 dimensional lumber was used as sheathing, and these 2x12 members were nailed to steel stakes driven into the ground. In front, a worker can be observed preparing some dimensional lumber by cutting it using a handsaw. It is to be noted that the worker is supporting the member on his foot rather than using a saw horse. The bottom half of the figure, towards the right, shows a prepared formwork panel serving as a support for the bracing for wall formwork (wall formwork not visible here). This shows use of formwork which the panel was not designed for.

Footing formwork used for portions of footing other than the strip footing can be seen in Figure 4.7. These forms were 2 ft high, and were made of plywood of 0.75 inch nominal thickness, supported by 2x4 members at the back. The number of uses the plywood had undergone was not known to the workers.

Figure 4.7: Footing Foundation, Project 2

Figure 4.8 and Figure 4.9 show the different types of formwork used in Project 3. Figure 4.8 shows the formwork used for the footings. These were assembled and erected using 1.125 inch thick plywood and 2x dimensional lumber, held together by bands. Again, the number of uses the plywood had under gone prior to use on this project was unknown.

The wall form systems used in Project 3, called gang forms, are seen in Figure 4.9. The bulkhead can be seen in the gap between the two halves of the wall form. These bulkheads were made out of new plywood initially, and the movement of the bulkhead forms was tracked and samples obtained for testing.

Figure 4.8: Footing Formwork, Project 3

Figure 4.9: Wall Formwork, Project 3

In all three projects, it was observed that the workflow in formwork use cycle is shortened version of the mapped workflow of general formwork use, and that each formwork use cycle onsite was different from the previous use cycle. Inclusion of storage and subsequently, the moving activities depended on the concrete placement schedule, as well as space and schedule constraints. Hence, there are several different workflows for formwork use in each project, and the mapped workflow generated for each project reflects several use cycles observed. The standards of worker safety observed were generally up to par, barring a few isolated instances and repetitive motions that may have an impact on health.

4.3. MAPPED WORKFLOW FOR FORMWORK USE

This section discusses the general formwork use cycle, as well as the project specific formwork use cycles obtained after monitoring the three projects. The use cycles are modeled as mapped workflows.

4.3.1. GENERAL MAPPED WORKFLOW

This section discusses the mapped workflow of one general formwork cycle. The workflow shows all possible activities that can possibly occur in one cycle of use, in a sequential manner, and can be seen in Figure 4.10.

One general cycle of formwork use consists of the following steps:

i. Stockpile - When different formwork components are transported to a project site, they are stored someplace on the project site by stacking them according to size, material type or other relevant criteria. Storage on site is typically done outdoors on pallets, and is stored uncovered.
ii. Prepare - In this step, the components are taken to a designated work area and cut to the dimensions desired to construct formwork as per project specifications.
iii. Move - This is an optional step, where the prepared components may or may not be moved elsewhere for assembly, or for assembly at a later date.
iv. Assemble – The prepared components are assembled into formwork panels using various connectors, such as nails, bolts, and clamps, driven by hand or by other mechanical means.
v. Stack/Stockpile – This is an optional step, where the assembled formwork panels may be stockpiled on site for use after site preparation.
vi. Move – In this step, the assembled formwork panels are moved to a different spot on the project site for erection at the point of use.
vii. Erect – For wall or column forms, the assembled formwork panels are raised into position around the reinforcing bars by hand, forklift, crane, or other means and fixed in place. For wall formwork, the opposing side of the formwork is placed next, and the two panels are connected using ties. For columns, the

panels on adjacent sides are placed, and the forms are fixed using bands, clamps, or other means of connection. Braces, stakes and any other necessary falsework for support are also installed.

viii. Pour – Concrete is poured into the constructed form, and vibrated internally or externally to consolidate the concrete.

ix. Cure – The concrete is left under ambient conditions of temperature and moisture to attain design strength.

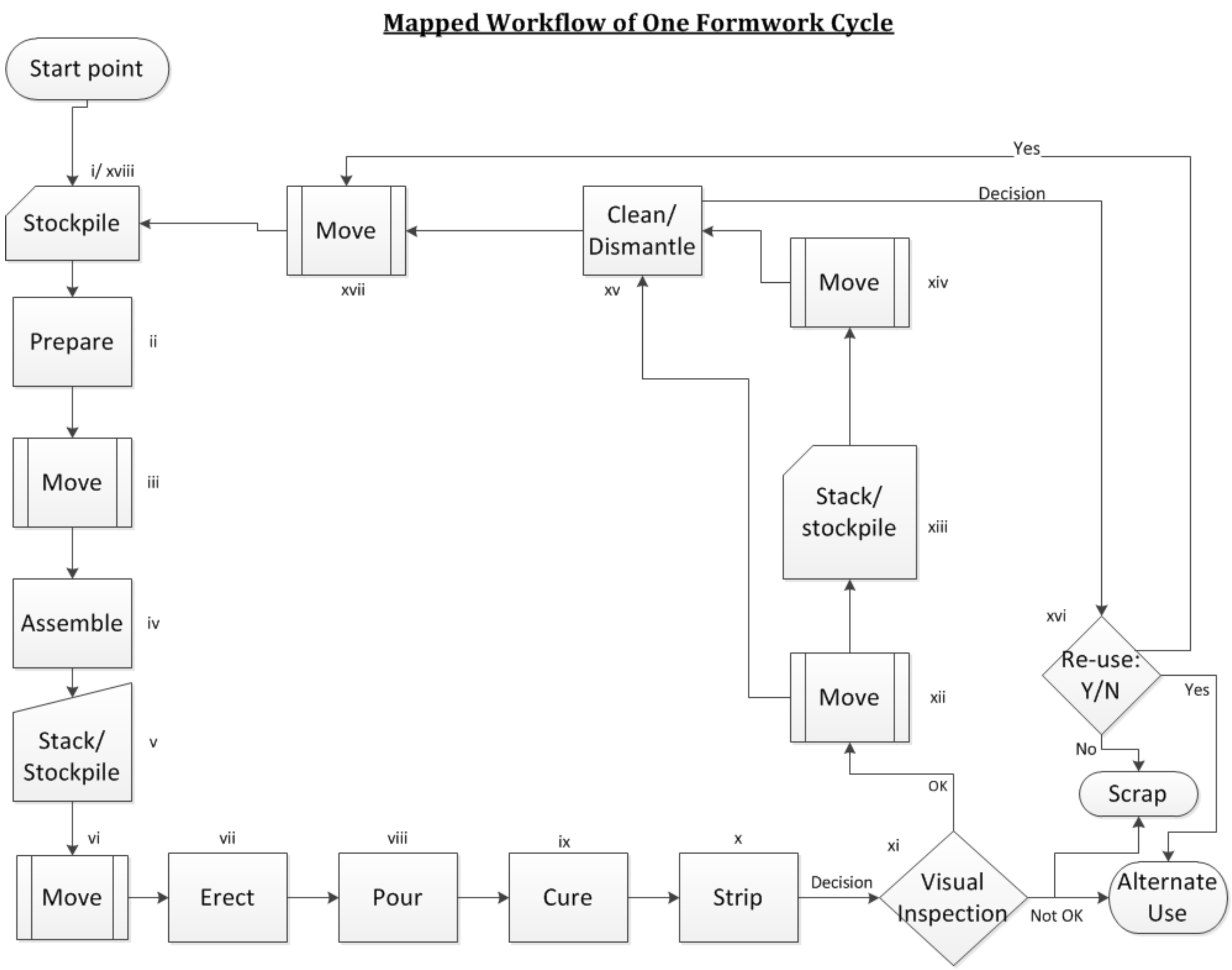


Figure 4.10: Mapped workflow for one general cycle of formwork use

x. Stripping – The stripping or striking of the formwork refers to the process of removal of the forms from the concrete after the concrete has attained the strength to carry its own weight. This process can be done by hand, or by mechanical means such as hydraulic jacks, forklifts, or cranes.

xi. Visual Inspection – The condition of the formwork is assessed by visual inspection, and the decision is made whether to use the formwork again, or not. If the decision is no, the formwork panel is disposed of into scrap, or put to an alternate use (not as formwork).

xii. Move – This is an optional step, where the formwork panels to be reused are moved.

xiii. Stack/Stockpile – In this step, the formwork panels fit for re-use are stored until the next instance of use or for cleaning/dismantling.

xiv. Move – This is an optional step, required only if the formwork has to be moved to a different spot for cleaning.

xv. Clean/Dismantle – The formwork panels are cleaned of the residual concrete and/or any other debris that may have accumulated, and oiled. Upon cleaning, further defects present on the formwork may be revealed. Otherwise, if the use of the panels on the particular project is over, they are dismantled for storage and transportation.

xvi. Decision to Re-use – The cleaned formwork panels are assessed again visually, to confirm that all components are sound and can produce the required surface finish. If any components are found unsuitable, they are replaced, and put into the scrap pile or to alternate uses.

xvii. Move – This is an optional step, where the panels can be moved elsewhere due to limited availability of space on the project site.

xviii. Stockpile – The cleaned panels are put aside till the next scheduled pour.

It is to be noted that it is not necessary that all steps explained have to be present in every formwork cycle. This general cycle can be modified to fit the formwork use cycle on any project and for any type of formwork by simply removing the steps that are not performed on the particular project.

4.3.2. PROJECT SPECIFIC MAPPED WORK FLOWS

The mapped workflows for each of the three projects monitored are explained in this section. For these project-specific workflows, it is to be noted that each figure has multiple formwork cycles depicted in it.

Figure 4.11 shows all the different formwork cycles observed during the course of Project 1. Any of the paths as set forth in the direction of the arrows can constitute one formwork cycle. For example, after erection, pouring, curing and stripping, visual inspection is done, and if any part of the formwork panel requires replacement, they would be replaced, and the panel cleaned and oiled. The cleaned panel may be erected immediately for the next use, or may be stockpiled somewhere on the site depending on the progress of work, and scheduled time of the next concrete pour. While the mapped workflow in Figure 4.10 shows one use cycle of formwork with all possible steps, Figure 4.11 shows the multiple workflows observed in Project 1, with the steps not required in the project removed.

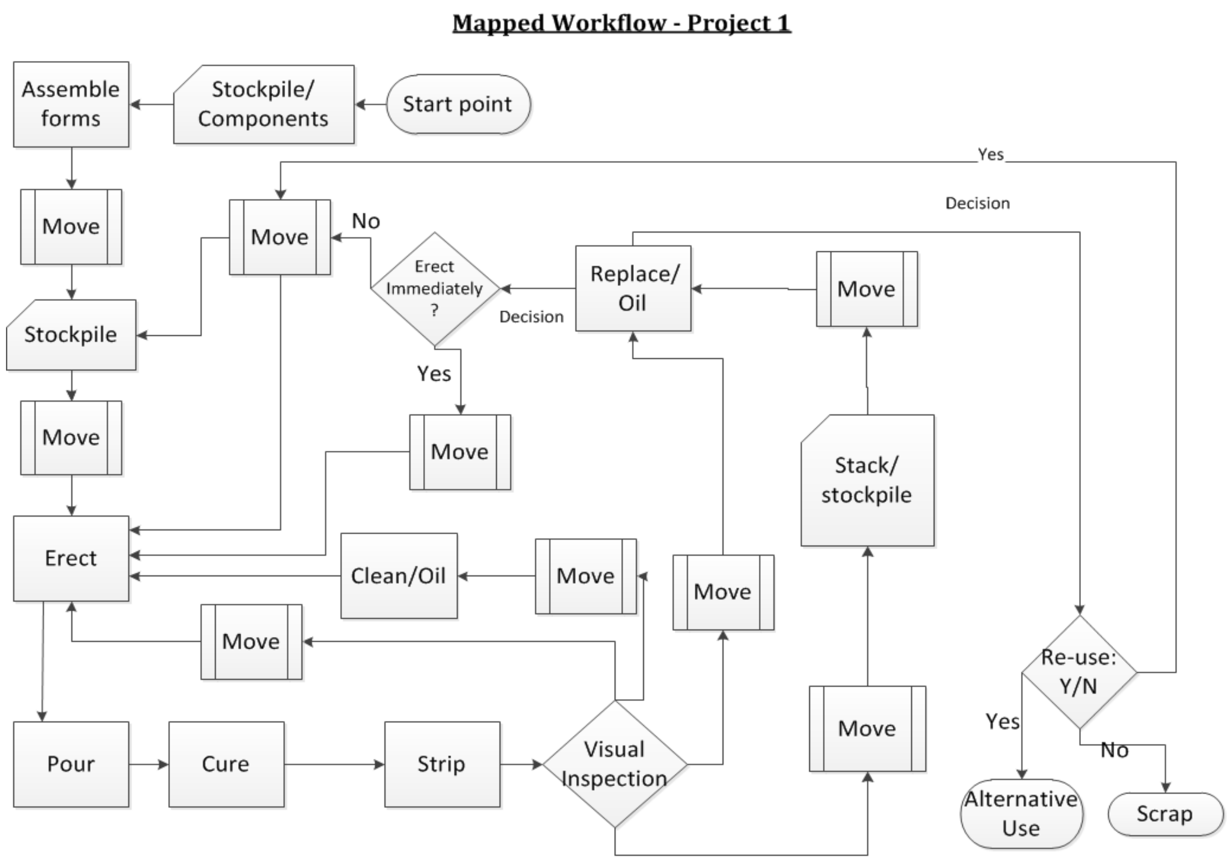


Figure 4.11: Mapped Workflows in Project 1

The second project monitored had very limited handset forms, and most of them were used for foundations. The stockpile form components were pre prepared and assembled when the day of pour was close, and erected immediately. After the concrete was poured and cured, the foundation forms were stripped the next day by hand, and forms from foundations of similar dimensions were taken to the next spot, cleaned and erected for the next pour. There were three different types of formwork observed on this project, but the workflow for the project (Figure 4.12) shows only the formwork cycles undergone by the handset wooden formwork. For mapping out the work flow, the other types of formwork were not taken into account.

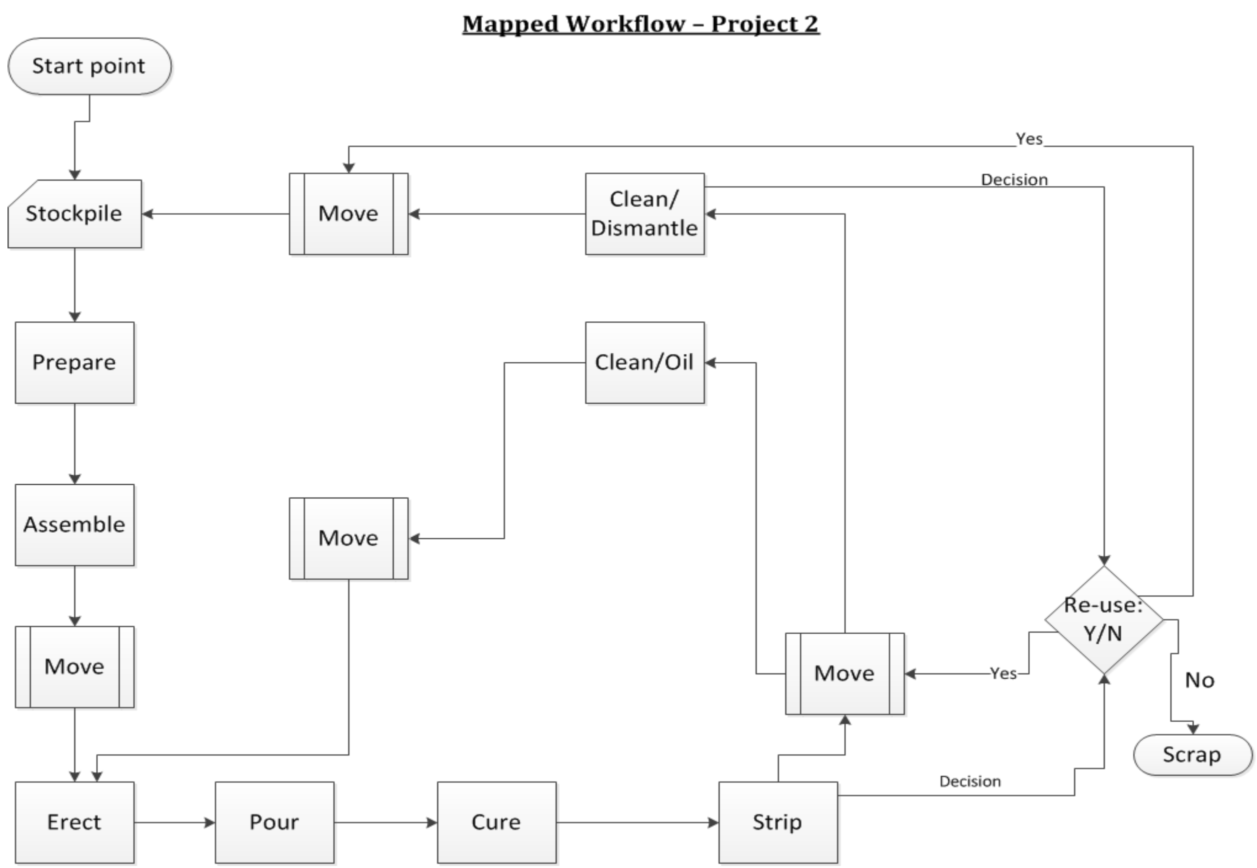


Figure 4.12: Mapped Workflows in Project 2

Similarly, there were two different types of vertical formwork observed in the third project – rented Aluma System forms, as well as handset forms. Handset forms were used in this project as foundation forms, as well as bulkheads on wall forms. The mapped workflow for this project shows the formwork use cycle for the handset wooden bulkhead forms. The first use cycle of the bulkheads is the stockpile-prepare-move-assemble-erect-pour-cure-strip-move-clean-move-stockpile sequence represented in Figure 4.13. The second and last use cycle for the bulkheads begin after the stockpile step in the previous cycle and follows the sequence of move-erect-pour-cure-strip, ending with the decision to re-use or not.

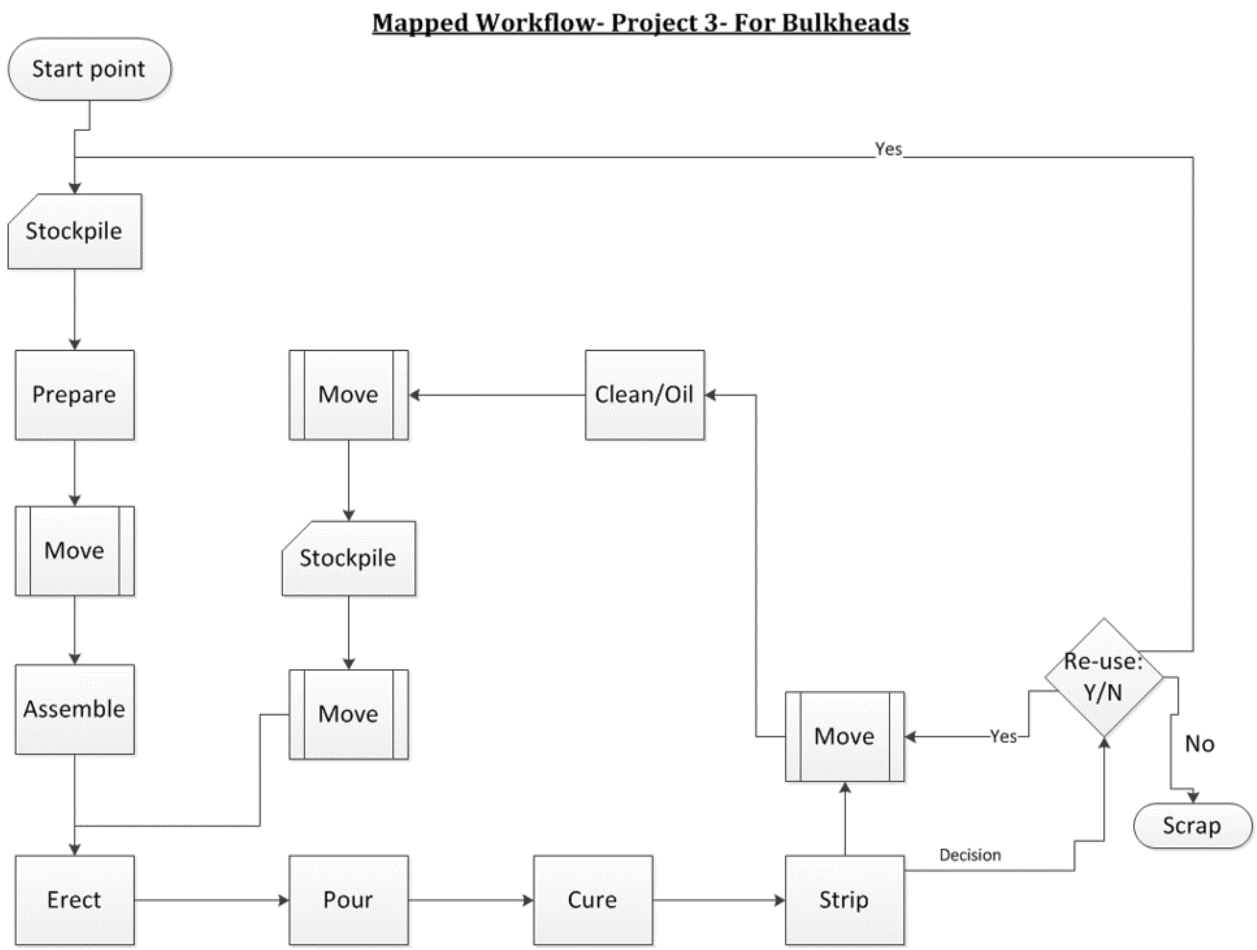


Figure 4.13: Mapped Workflows in Project 3

4.4. OSHA CASE STUDY RESULTS

In order to assess worker safety risks associated with formwork, it was deemed necessary to collect and analyze data from publically available OSHA Fatality and Catastrophe Investigation Summaries so as to obtain an idea of the typical causes of injury associated with formwork. In the list of workplace injuries, illnesses, and fatalities available on the OSHA recordable incident database, there are 438 cases associated in some way with concrete formwork from 1984 to 2012. All 438 case summaries were reviewed to understand the proportion of risk associated with each activity in the formwork cycle. A detailed statistical summary of the number of incidents can be seen in Table 4.1.

Table 4.1: OSHA Incident statistics according to Severity and Activity

Activity		Assembly	Erection	Forming	Transportation	Pouring Concrete	Stripping	Other	Not Specified
Near Miss	**No. of incidents**	0	0	0	0	1	0	0	1
	% of total*	0.00%	0.00%	0.00%	0.00%	0.89%	0.00%	0.00%	5.00%
Low Severity	**No. of incidents**	1	4	1	1	6	3	3	1
	% of total*	5.00%	4.12%	2.38%	7.14%	5.36%	3.41%	6.67%	5.00%
Medium Severity	**No. of incidents**	9	49	13	4	62	41	18	7
	% of total*	45.00%	50.52%	30.95%	28.57%	55.36%	46.59%	40.00 %	35.00%
High Severity	**No. of incidents**	10	44	28	9	43	44	24	11
	% of total*	50.00%	45.36%	66.67%	64.29%	38.39%	50.00%	53.33 %	55.00%
Total Number of incidents / activity		20	97	42	14	112	88	45	20
	% of Net total**	4.57%	22.15%	9.59%	3.20%	25.57%	20.09%	10.27 %	4.57%

Legend:
* 'total' refers to the total number of incidents related to each activity
** 'Net total' refers to the total number (438) of incidents recorded, which are related to formwork use

Out of 438 incidents, 2 incidents were Near Misses (disruptive incidents that resulted in no injury, but had a significant impact on the project), 20 were of Low Severity (temporary discomfort/pain or minor first aid required, with limited impact on work time, but had significant impact on the project), 203 incidents of Medium Severity (major first aid required or medical case, along with lost work time greater than a day), and 213 incidents of High Severity (incidents leading to permanent disability or fatality), out of which 177 incidents were fatalities. It is to be noted that in Table 4.1, 'total' refers to the total number of incidents related to each activity, while 'Net total' refers to the total number of incidents recorded which are related to formwork use, and is equal to 438. The distribution of injuries for each activity in the formwork cycle is shown in Figure 4.14.

Table 4.2 and Figure 4.15 show the number of fatalities associated with each activity, relative to the number of incidents of High Severity level associated with each activity. The largest number of fatalities (40 fatalities, 93.02% of High Severity incidents) has been reported for the activity of Pouring Concrete. It is worth noting that although it is not possible to distinguish between horizontal formwork and vertical formwork in many cases, most incidents of high severity related to Pouring Concrete occurs during the use of horizontal formwork.

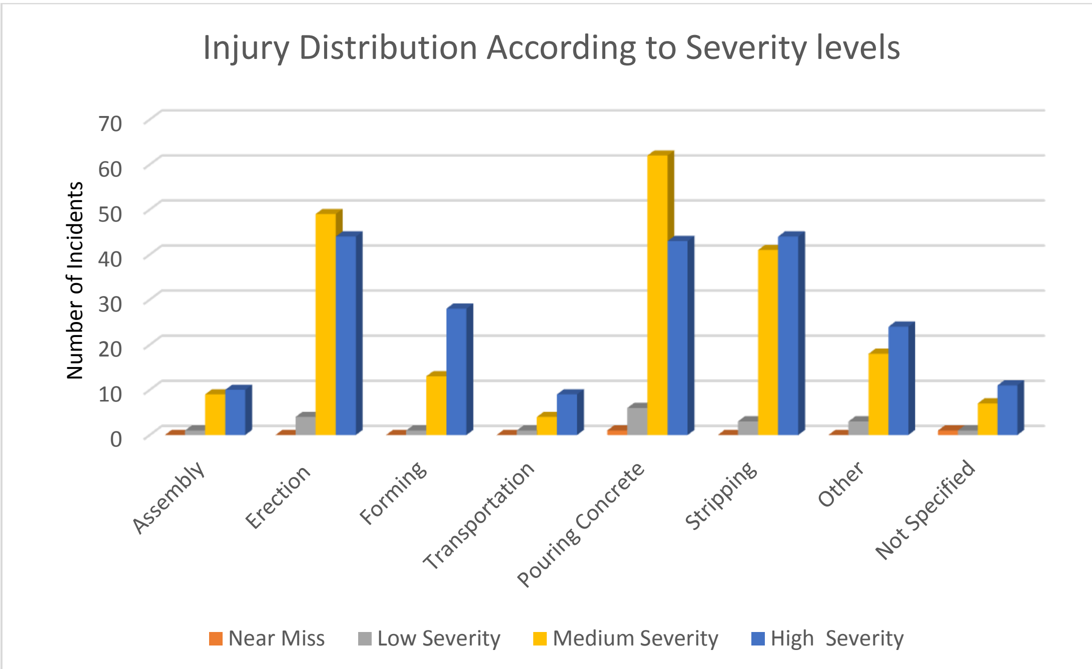


Figure 4.14: Number of Incidents categorized by Activities

The number of fatalities was also classified according to the activity being performed at the time occurrence of the incident. The percent of fatalities relative to the number of incidents of high severity, as well as to the number of total incidents in each category can be found in Table 4.2. As seen in Figure 4.16, the activity with the largest number of fatalities was Pouring Concrete (40 fatalities) followed by Stripping (38 fatalities). Other activities with a large number of fatalities were Erection of formwork (29 fatalities) and Forming (22 fatalities). The Other category (23 fatalities) specifies incidents in which the worker involved in the incident was performing another activity completely independent of any concrete forming activities. The Not

Specified category contains the number of incidents in which it is not possible to determine the ongoing activity due to a lack of detail in the summary.

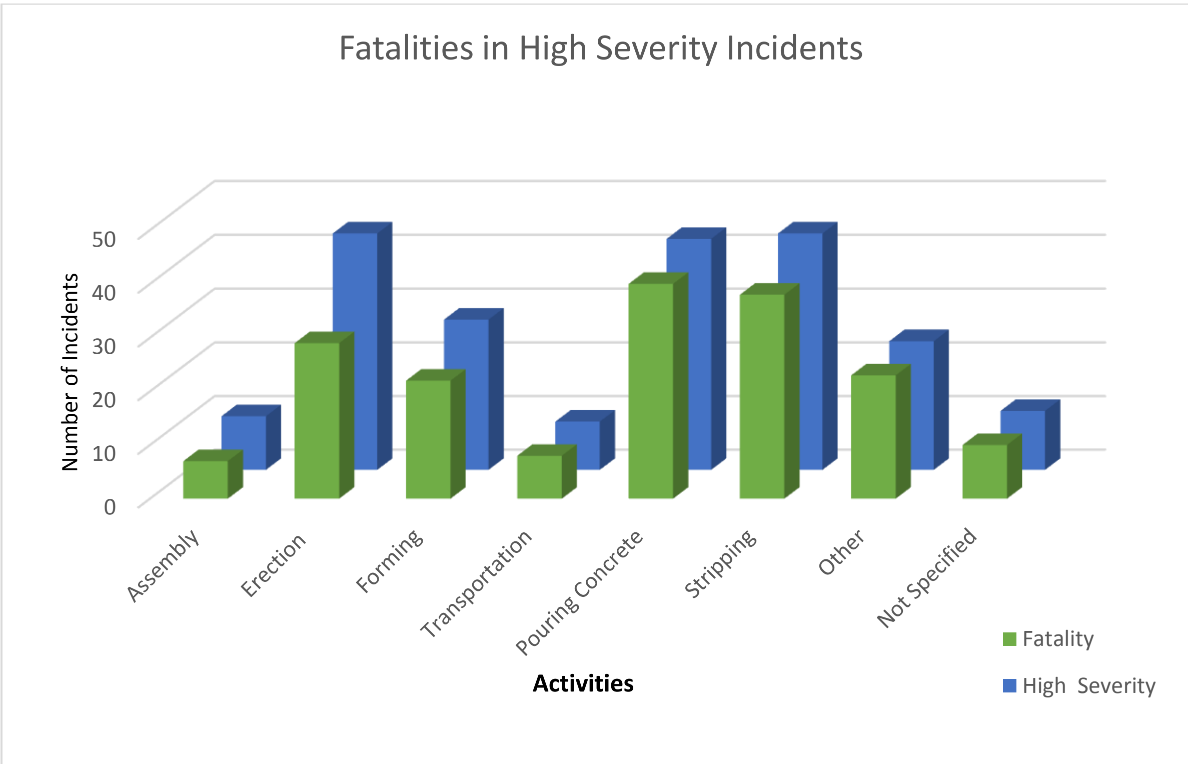


Figure 4.15: Fatalities Relative to High Severity Incidents

Table 4.2: Fatalities associated with each activity, relative to High Severity

Activity		**Assembly**	**Erection**	**Forming**	**Transportation**	**Pouring Concrete**	**Stripping**	**Other**	**Not Specified**
High Severity	**No. of incidents**	10	44	28	9	43	44	24	11
Non-fatality	**No. of incidents**	3	15	6	1	3	6	1	1
Fatality	**No. of incidents**	7	29	22	8	40	38	23	10
	% of High	70.00%	65.91%	78.57%	88.89%	93.02%	86.36%	95.83%	90.91%

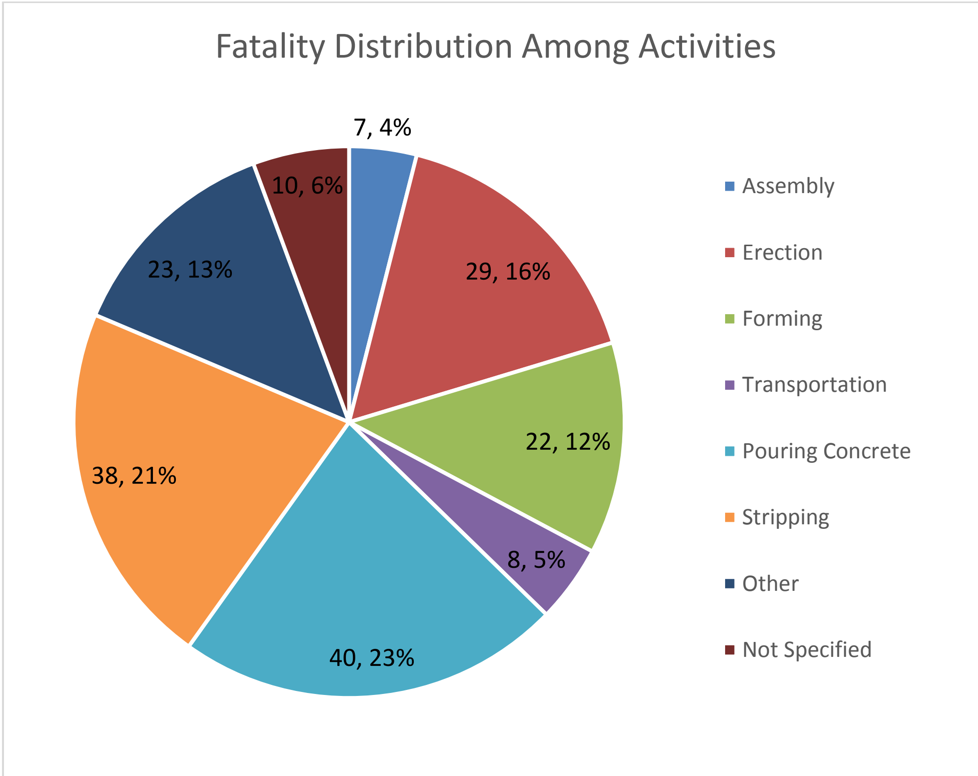


Figure 4.16: Percent of Fatalities in each Activity Category

The lower number of Near Misses and Low Severity injuries could be attributed to the fact that most incidents which meet the definitions for these types of injuries do not fall into the category of an OSHA recordable injury. Since OSHA Fatality and Catastrophe summaries do not provide in-depth detail of every incident, in many cases, it is not possible to determine the exact conditions and type of formwork being worked on at the time of incident, i.e., horizontal formwork or vertical formwork, the safety culture, surrounding hazards, and the specific activity performed by the worker involved in the incident. Most importantly, the root cause of the incident itself is not described in detail. The case summaries in some incidents do not give a clear idea of the accident scenario, which could lead to the incident being assigned to a different severity level. It worth noting that for some incidents there was just sufficient information available to understand that the employee was engaged in preparation, assembly, or erection of formwork during the occurrence of the incident, but not enough to assign the incident specifically to any of the mentioned activity categories. For such cases, the activities were assigned to the activity of Forming, which comprises both Assembly and Erection activities.

4.5. LABORATORY TESTING RESULTS

The results obtained from the bending tests (Third point bending) and rolling shear tests (Five point bending) of the formwork specimens prepared from samples collected from the monitored projects are presented in this section.

4.5.1. THIRD POINT BENDING (BENDING)

Plywood specimens of 0 uses, 2 uses, 5 uses, 8 uses, 11 uses and 14 uses were tested from Project 1, and the maximum load and the induced bending stress values obtained are shown in this section. The test statistics of average maximum load and average maximum bending moment per use, for all specimens prepared from Project 1 samples can be seen in Table 4.3, corresponding to Figure 4.17 and Figure 4.18 respectively.

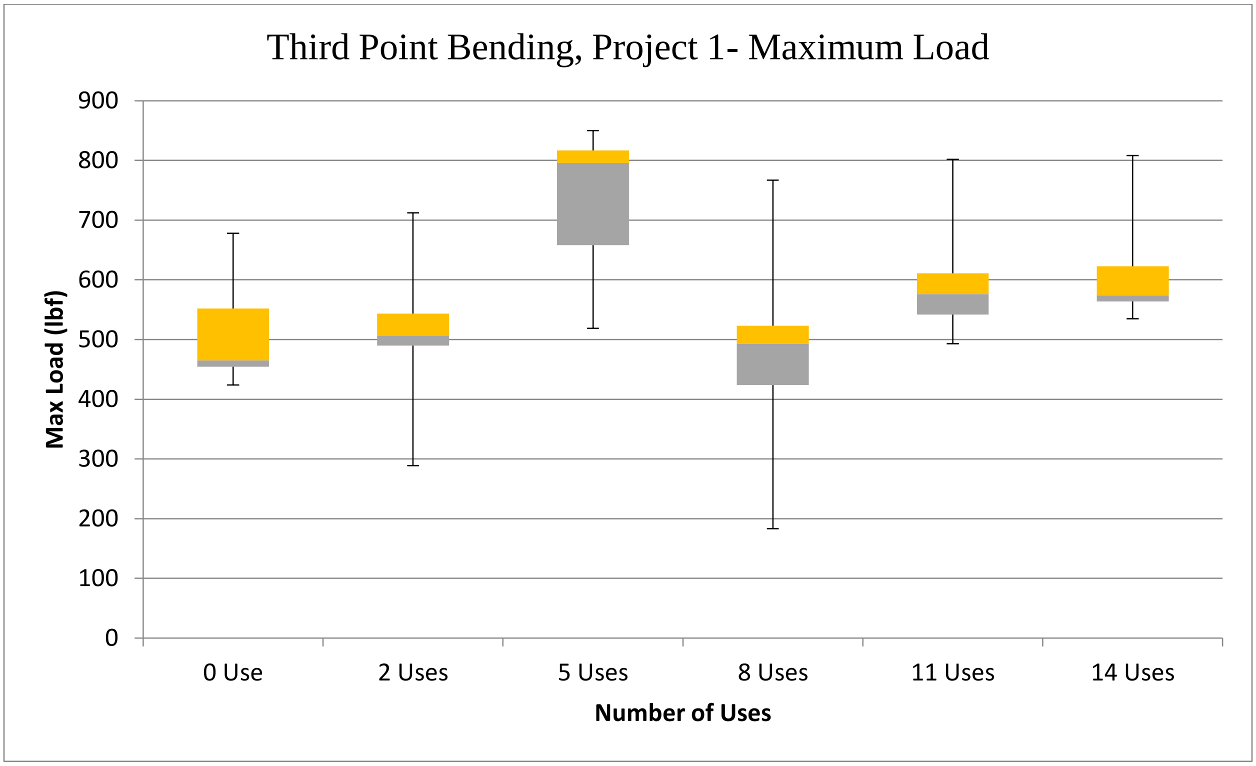


Figure 4.17: Box Plot, Maximum Load from Bending tests, Project 1

It can be seen that the average maximum load decreases from 0 uses to 2 uses, increases to the highest value at 5 uses, and comes down to the lowest value at 8 uses. The average maximum loads for 11 uses and 14 uses are close, falling lower than the value for 5 uses, yet above the average maximum load value for 0 use. The test statistics for average bending moment per use follow the same trend as the average maximum load: the highest average bending moment value corresponded to 5 uses, followed by 14 uses, 11 uses, 0 uses, 2 uses, and 8 uses at the lowest. The median value trend is the same as the mean value trend in both cases.

Table 4.3: Test Statistics for Third point bending tests, Project 1

# of Uses	Mean Max Load	Std Dev. Max Load	Mean Bending moment	Std Dev. Bending moment	COV
	(lbf)	(lbf)	(lbf.in)	(lbf.in)	%
0	513.8	85.47961	2226.55	370.41	17.01425
2	501.3	106.6865	2172.18	462.31	21.76684
5	743.8	107.9378	3223.21	467.73	14.84111
8	484.0	148.5254	2097.33	643.61	31.3845
11	593.9	88.1311	2573.61	381.90	15.17641
14	605.7	80.25222	2624.82	347.76	13.55001

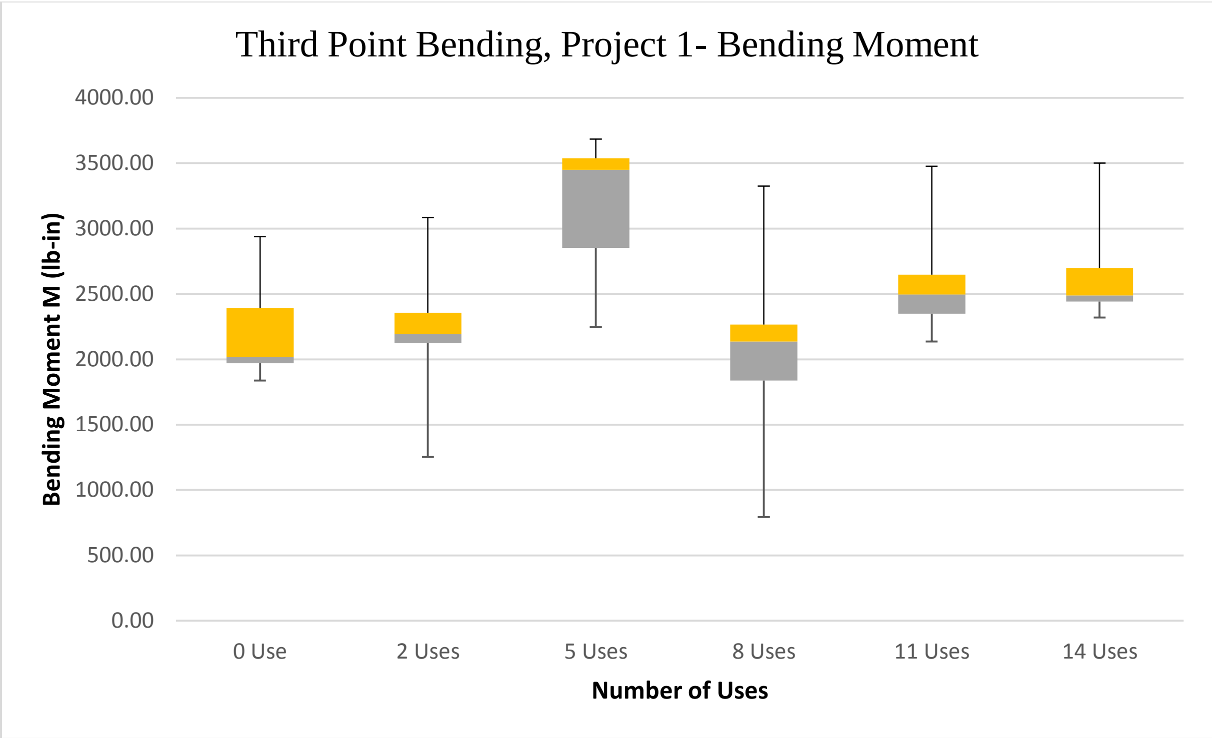


Figure 4.18: Box Plot, Calculated Bending Moment from Bending tests, Project 1

The test statistics for the average maximum load per use and the calculated bending moment per use for specimens prepared from Project 3, using Third point bending tests can be viewed in Table 4.4. The corresponding box plots can be seen in Figure 4.19 and Figure 4.20 respectively. The test statistics for maximum load show that specimens with 0 uses had the highest average capacity, followed by samples with 2 uses, and finally with 1 use. However, the median maximum load shows a slightly different trend, with 0 uses being the highest, followed by 1 use, and then 2 uses.

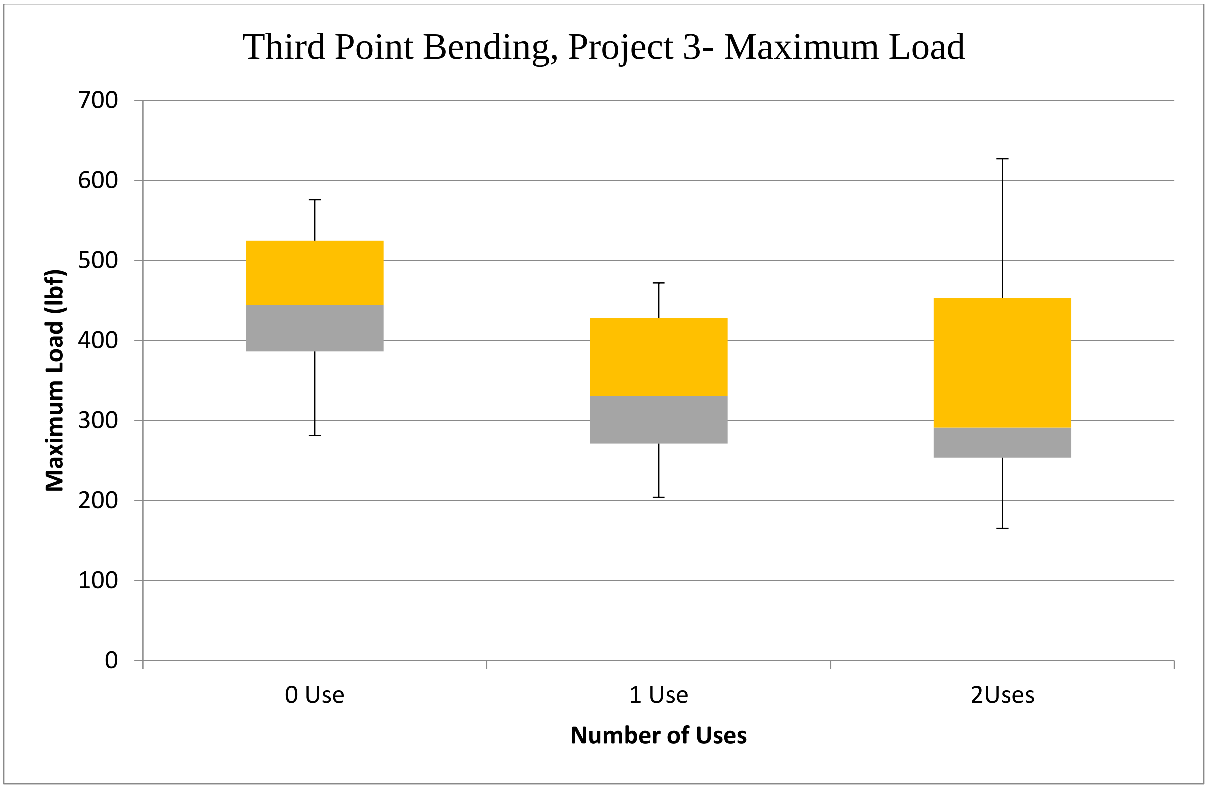


Figure 4.19: Box Plot, Maximum Load from Bending tests, Project 3

Table 4.4: Test Statistics for Third Point bending tests, Project 3

# of Uses	Mean Max Load/use	Std Dev. Max Load/Use	Mean M/use	Std Dev. M/Use	COV
	(lbf)	(lbf)	(lbf.in)	(lbf.in)	%
0	443.00	96.37	1605.88	349.34	22.21
1	337.50	91.62	1223.44	332.11	27.71
2	347.71	135.09	1260.46	489.69	39.66

The test statistics for the average bending moment per use for specimens prepared from Project 3, calculated using the maximum loads obtained can be viewed in Table 4.4 and Figure 4.20. The test statistics for bending moment exhibit the same trend, in descending order - 0 use, 2 uses, and 1 use – and the value of the median bending moment is 0 uses being the highest, followed by 1 use, and then 2 uses.

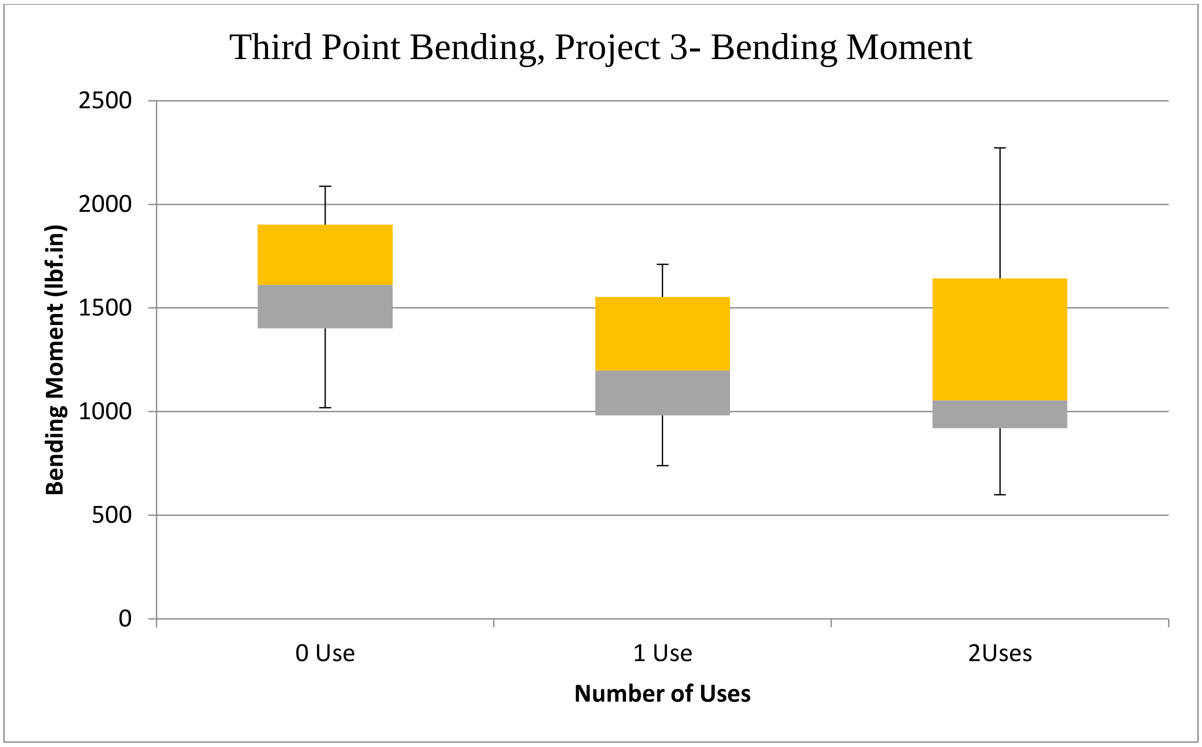


Figure 4.20: Box Plot, Calculated Bending Moment from Bending tests, Project 3

4.5.2. FIVE POINT BENDING (SHEAR)

The test statistics for the average maximum load per use and the induced shear stress per use for specimens prepared from Project 1 tested using five point bending shear tests can be viewed in Table 4.5, and the corresponding box plots can be seen in Figure 4.21 and Figure 4.22. The test statistics for maximum load show that specimens with 8 uses had the highest average capacity, followed by samples with 5 uses, 0 uses, 2 uses, 11 uses, and finally with 14 uses, in the descending order. The median values also show the same trend.

The test statistics for average induced shear stress show that specimens with 8 uses had the highest average capacity, followed by samples with 5 uses, 0 uses, 2 uses, 14 uses, and finally with 11 uses, in the mentioned order. The median values follow a different order - 5 uses, 8 uses, 0 uses, 2 uses, 11 uses, and 14 uses – in descending order of magnitude.

Figure 4.21: Box Plot, Maximum Load from Rolling Shear tests, Project 1

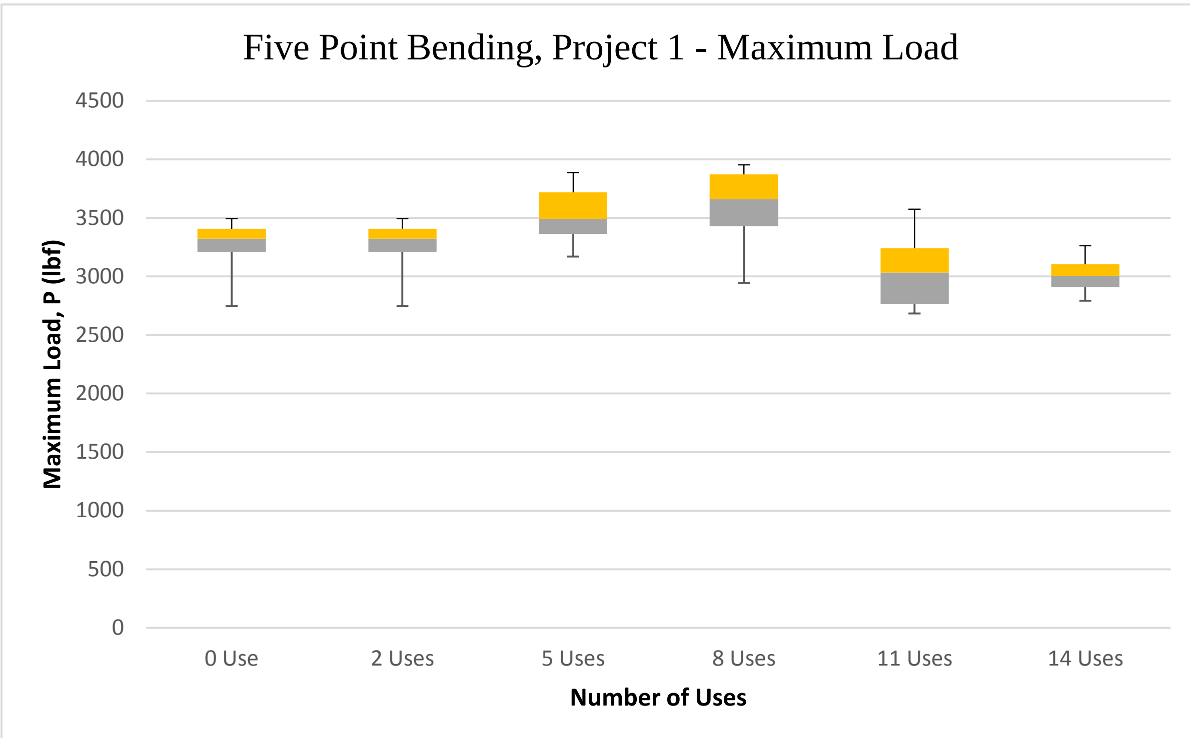


Table 4.5: Test Statistics for Five point bending tests, Project 1

# of Uses	Mean Max Load/Use	Std Dev. Max Load/Use	COV	Mean Induced Shear stress/ Use	Std Dev. Induced Shear stress/Use	COV
	(lbf)	(lbf)	%	(psi)	(psi)	%
0	3517.88	169.06	4.91	533.03	27.97	5.38
2	3266.78	230.39	7.21	487.94	30.56	6.42
5	3539.76	234.60	6.78	551.13	39.16	7.28
8	3608.45	319.11	9.04	554.16	51.83	9.59

# of Uses	Mean Max Load/Use	Std Dev. Max Load/Use	COV	Mean Induced Shear stress/ Use	Std Dev. Induced Shear stress/Use	COV
11	3035.26	298.89	10.07	443.24	37.85	8.75
14	3025.93	157.74	5.33	463.07	33.46	7.41

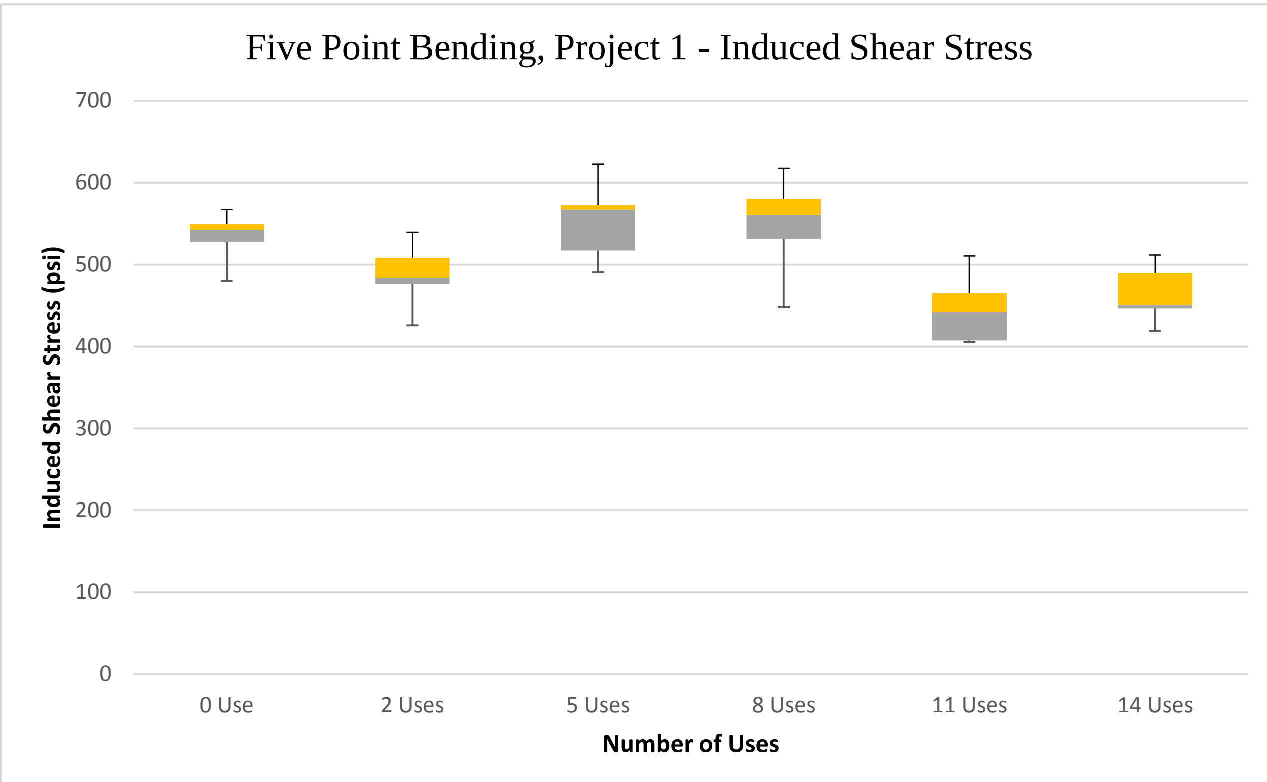


Figure 4.22: Box Plot, Induced Shear Stress from Rolling Shear tests, Project 1

The mean maximum load per use and induced shear stress per use for specimens prepared from Project 3 samples, obtained by five point bending, have the test characteristics shown in Table 4.6. The corresponding boxplots can be found in Figure 4.23 and Figure 4.24 respectively. The magnitude of the test value for the average maximum load per use, in descending order, is :1 use, 2 uses, and 0 use. The median values also exhibit the same trend.

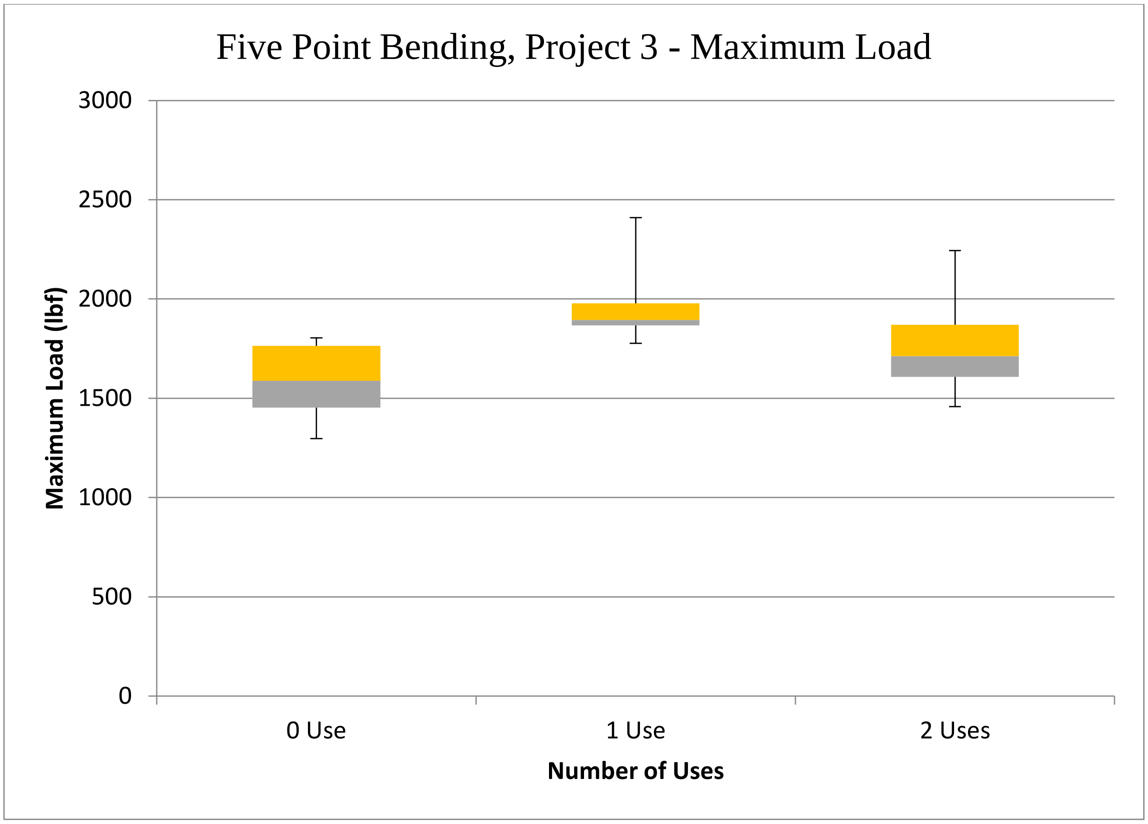


Figure 4.23: Box Plot, Maximum Load from Rolling Shear tests, Project 3

Table 4.6: Test Statistics for Five point bending tests, Project 3

# of Uses	Average Max Load/Use	Std Dev. Max Load/use	COV	Average Induced Shear Stress	Std Dev. Induced Shear Stress	COV
	(psi)	(psi)	%	(psi)	(psi)	%
0	1628.37	148.93	9.34	399.85	191.85	48.98
1	1891.56	63.02	3.40	468.87	219.90	47.88
2	1675.36	146.24	8.91	405.15	191.63	48.28

For the average induced shear stress per use for specimens prepared from Project 3, the trend of mean and median values exhibited is the same as the trend exhibited by the average maximum load for Project 3 specimens obtained by five point bending tests - 1 use, 2 uses and 0 uses – in the decreasing order of magnitude.

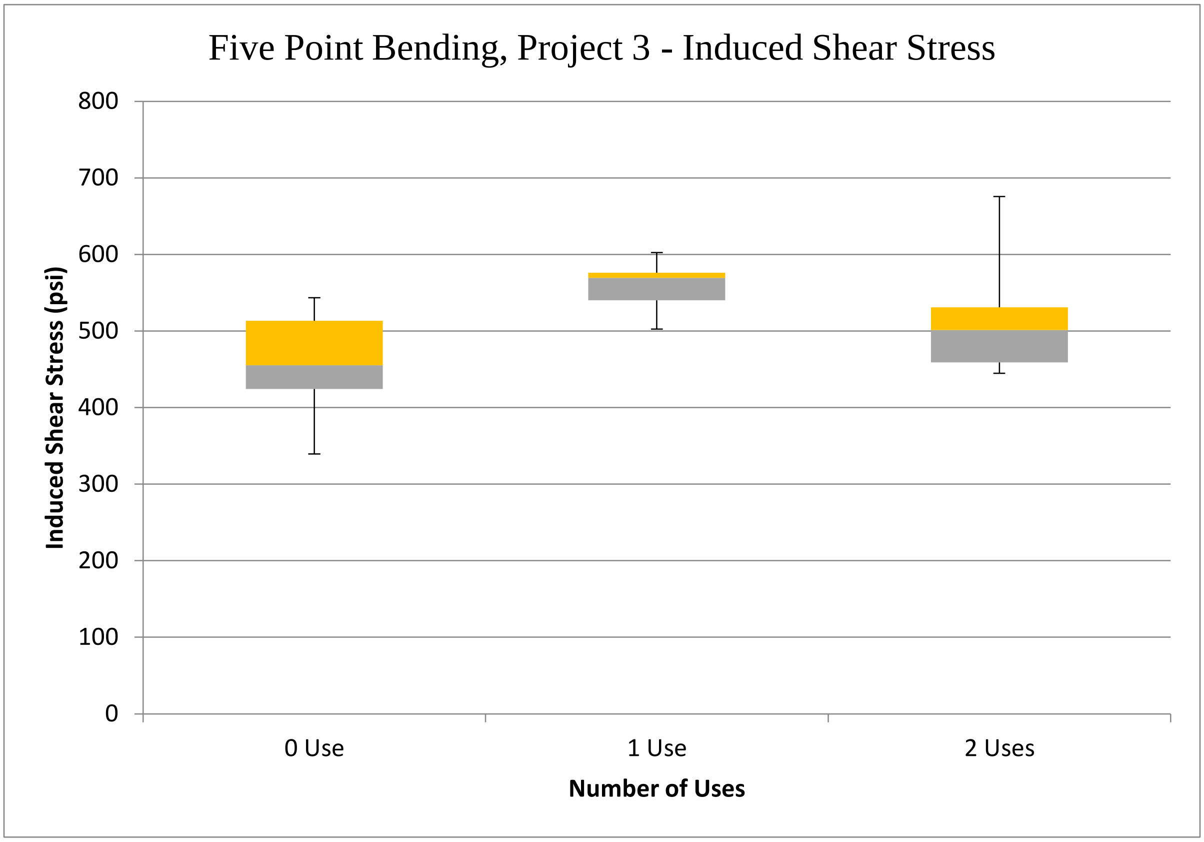


Figure 4.24: Box Plot, Induced Shear Stress from Rolling Shear tests, Project 3

4.5.3. DISCUSSION OF TESTING RESULTS

The testing results, presented in Chapter 4, exhibit no particular trend. The expected trend was that the sample specimens with lower number of uses would exhibit higher capacity, with specimens of 0 uses having the maximum value. However, this was not observed in the testing. The possible reasons for this are discussed in this section.

It was found that keeping track of the number of uses is not something usually done in the industry. In the cases where sheets of plywood were used for the first time on any of the three projects, it was possible for the research team to track the number of uses the plywood was subjected to. The primary reason for not conducting any testing on the sample panels obtained from Project 2 was that apart from the new sheets of plywood, there were no means available to identify with any certainty the number of uses that the used plywood panels had been subjected to.

From both projects, samples were collected as panels of varying sizes, and there was often only one panel with a certain confirmed number of uses available. The variation of properties in plywood can be large, as can be seen from the large coefficients of variation obtained by testing specimens prepared from one or two panels. In addition to this, there could be even more unaccounted variation introduced into the test data as the samples of different uses obtained could have come from different sources, as the samples may be made out of different types of wood, glue or manufactured in a different way. It is assumed that the sample panels at least come from the same manufacturer, as companies use the same supplier for plywood through extended periods of time. Even then, it is not necessary that all samples belong to the same batch.

In this study, significant variations were observed in the dimensions of the specimens prepared from the obtained samples, and the variation in thickness of the sample specimens. These variations were accounted for by measuring the thickness and width of each specimen at four different points on the specimen and using an average value thus obtained for subsequent calculations. All the tests were set up and carried out by the same operator in an effort to minimize variations in the testing method and the test setup.

Additionally, from the formwork monitoring, it was observed that some formwork panels had different exposure patterns depending on the concrete pour schedule and the weather conditions. Some forms were exposed to rain and to additional stresses during storage, such as workers climbing on them. Furthermore, some formwork panels were subjected to alternate use before being reused (For example, formwork panel being used as a work platform). Variations due to these exposures are not accounted for in the testing.

CHAPTER 5. RISK AND RELIABILITY ASSESSMENT

This section contains the details of the risk and reliability calculations performed based on the obtained data. It contains a summary of the results of the safety risk survey, a discussion and analysis of the survey results and the risk model developed in @Risk, and the reliability assessment performed using the testing results and other calculations.

5.1. SAFETY RISK SURVEY

Thirty two responses were obtained from safety surveys and analyzed. The results of the survey are summarized in this section. All respondents worked on different construction projects in Northwest Oregon, and were members of the Pacific Northwest Regional Council of Carpenters (PNRCC). Additionally, all respondents belonged to the carpentry trade, as carpenters work with formwork on the majority of projects. The first section of the survey gathered information about trade, affiliated organization, and number of years of experience. The statistics for the number of years can be seen in Figure 5.1. Twenty-five percent of the respondents had 25 or more years of work experience. The next section of the survey, which is the main section of the survey, asked the respondents to rate the frequency of injuries of different severities as well as the time spent by the worker working on each activity.

A portion of the safety survey with example responses can be seen in Table 5.1. As seen in the mapped workflow for general formwork use, there are 18 steps, out which 13 activities were deemed to pose some amount of risk to the workers involved. Each row in the survey corresponds to an activity, in sequential order. The first column to be filled in asks the respondents to enter the percent of time spent working on each activity. The second column requires the frequency of near miss incidents, rated according to the frequency scale provided in Chapter 3. Similarly, the third, fourth and fifth columns ask the respondent to fill in the frequency of low, medium, and high severity incidents corresponding to the activities in each row.

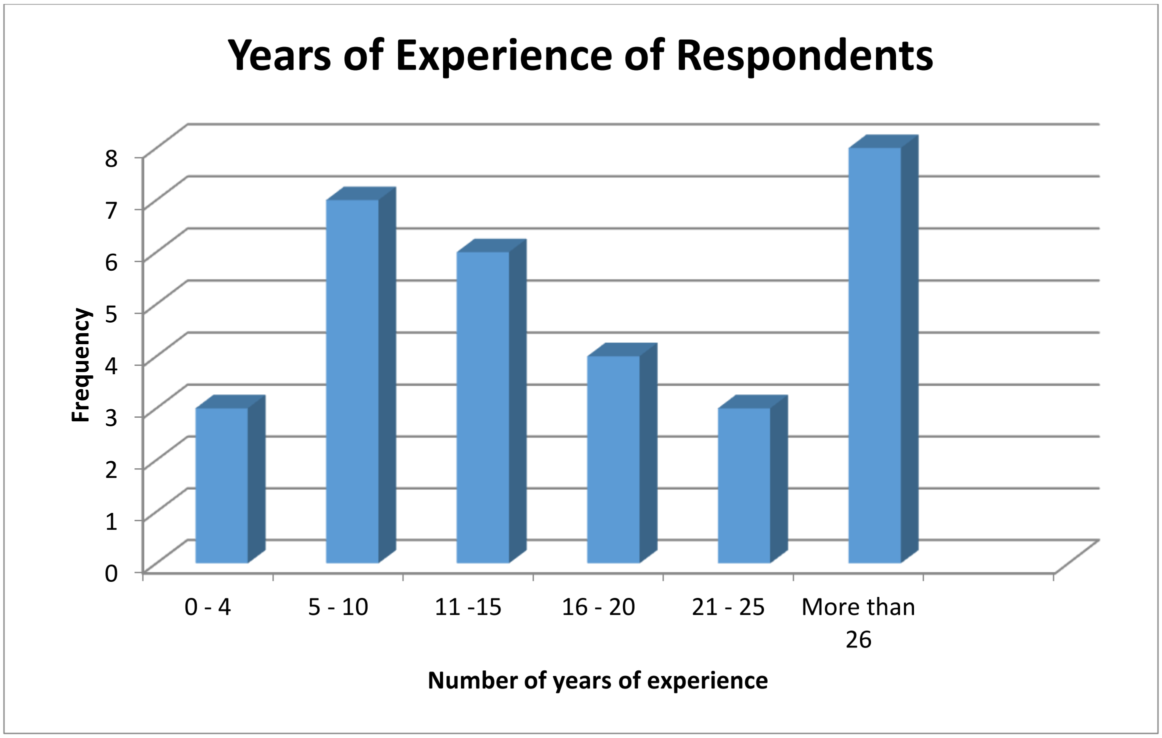


Figure 5.1: Experience of Respondents, in years

Table 5.1: Sample of Safety Survey Response (Partial)

ACT. NO.	ACTIVITY EXPOSURE* (%)	ACTIVITY	ACTIVITY DESCRIPTION	POSSIBLE FREQUENCY OF INJURY (Frequency of injury on a scale of 0 – 10)			
				Near Miss	Low Severity	Medium Severity	High Severity
	20	Moving	Unloading and carrying plywood/wood/other form components from trucks to stockpile on site	7	5	4	2
	40	Preparation	Cutting plywood/2x's into the necessary sizes and shapes required to construct a formwork panel using a handsaw, saw horses, etc.	9	7	5	3

*The total sum of exposures does not need to add up to a 100%

Average frequency values were calculated, and the average exposure of respondents to the risk associated with each activity was calculated. The mean responses obtained for each of the five input columns are displayed in Table 5.2. It can be seen that the largest value for exposure is 40%, for assembling forms (Activity No. 4), meaning the respondents, as an average, perceive that the longest duration of exposure to any existing risk occurs during the activity of assembling forms. The highest average frequency value is 6, or an incident every six months for near miss incidents during the activity of Moving. The average is calculated here rather than the median or mode, as the available responses would be further used as inputs into the risk simulation software @Risk, to obtain the total unit risk and the total cumulative risk, as well as to identify the activities that affect the total risk values the most.

Table 5.2: Average Values of Responses obtained

Act. No.	Activity	AVERAGE				
		Activity Exposure	Near Miss (Severity/ incident)	Low Severity (Severity/ incident)	Medium Severity (Severity/ incident)	High Severity (Severity/ incident)
1	Stockpile	15.56	5.33	4.89	3.22	1.78
2	Preparation	37.78	5.00	5.11	3.56	2.11
3	Moving (Optional)	32.22	6.00	5.67	3.44	2.00
4	Assembling Forms	40.00	5.56	5.00	3.33	2.22
5	Stacking Prepared Forms	17.78	5.22	5.00	3.33	1.67
6	Moving	15.56	5.11	5.00	3.67	2.22
7	Erection/Placing Forms	34.44	5.67	5.00	3.56	2.56
8	Pouring Concrete/Curing	20.56	4.67	4.33	3.00	2.33
9	Stripping Forms	25.56	5.67	5.33	3.33	2.00
10	Move forms	16.67	5.44	4.67	3.33	1.56

Act. No.	Activity	AVERAGE				
		Activity Exposure	Near Miss (Severity/ incident)	Low Severity (Severity/ incident)	Medium Severity (Severity/ incident)	High Severity (Severity/ incident)
11	**Dismantling/ Cleaning Forms**	15.56	4.78	4.11	2.78	1.11
12	**Move forms/ Form Components**	20.00	4.89	4.33	3.00	1.44
13	**Stack/ Stockpile Forms**	17.22	5.11	4.56	3.44	1.56

The final section of the safety survey posed an open ended question to the respondents regarding the factors that increase or decrease the risk of injury while working with formwork. The most frequent responses obtained were tabulated and can be seen in Table 5.3. A summary containing the responses obtained from the safety survey can be viewed in Appendix III-B.

Table 5.3: Factors that affect risk of injury

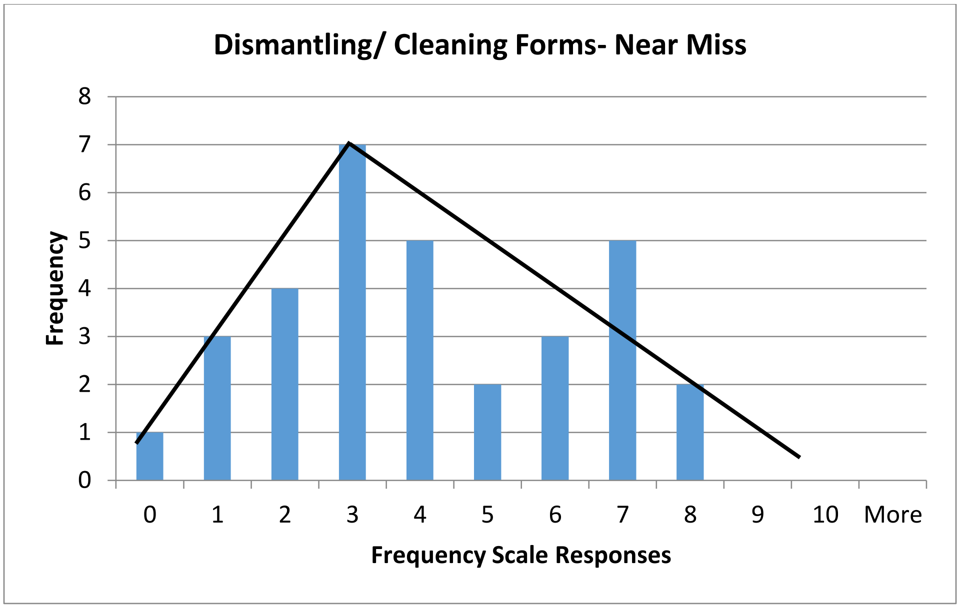
Factors that increase the risk of injury	**Factors that decrease the risk of injury**
Weather Conditions	Pre-task planning
Tight Schedule	Collect tools and supplies
Drug/Alcohol abuse	Effective communication
Lack of proper tools/ equipment	Good Morale
Lack of sleep	Proper access and use of proper safety gear
Lack of experience, training	Sufficient sleep
Lack of Communication	Team work
Lifting too much weight	Clean/Tidy site

5.2. RISK ASSESSMENT

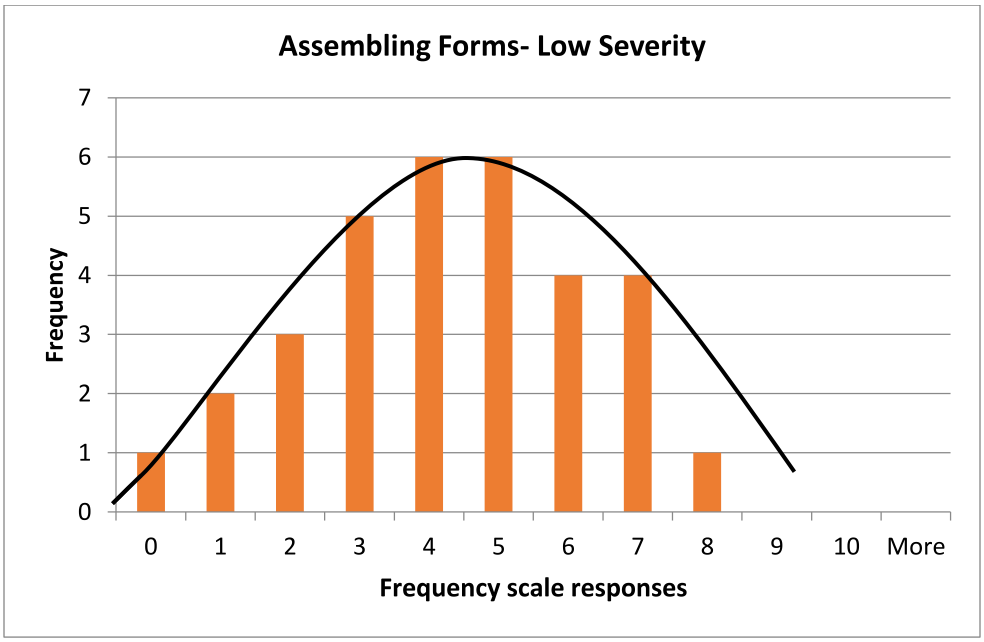
Assessment of the risk to workers carrying out various formwork use activities was carried out using a safety survey. The responses obtained were used to calculate quantitative unit risk and cumulative risk values for each activity, as well as to calculate total unit risk and total cumulative risk for an entire formwork use cycle. One variable was obtained from the frequency response for each activity and severity level, making it 52 variables in total. In addition to these 52 frequency variables, the exposure for each activity was also considered. Thus, the total number of variables was 65.. Each variable was assigned an appropriate probability distribution functions (PDF). To do so, histograms of each of the variables were examined, and an appropriate PDF assigned by shape. For additional validation, cumulative distribution plots showing the empirical cumulative distribution against the expected cumulative distribution were constructed for each variable to confirm that the distribution used is appropriate. From the histograms, it is visible that the frequency values for each severity level approximately follow the same trend.

In the case of Near misses, the histograms showed no particular trend, and did not seem indicative of the commonly used normal or lognormal PDF. PERT (Program Evaluation and Review Technique) and Triangular distributions are very widely used to model uncertainties during risk modeling. The PERT distribution is similar to the normal distribution, the main difference being that additional weight is given to the mean or expected value during calculations. The triangular PDF is a triangularly-shaped distribution, and requires the maximum, minimum, and most likely value as distribution parameters. The model has been set up in such a way that the frequency value for variables in the four different severity levels are always within the range of 0 and 1, while the exposure values are set up to never go below 0. The histograms and cumulative distribution plots for determining the appropriate PDF can be found in Appendix III-A and B respectively. An example of histograms obtained has been provided below to demonstrate the distribution trend in each category. The following PDF were assigned to variables of each severity level:

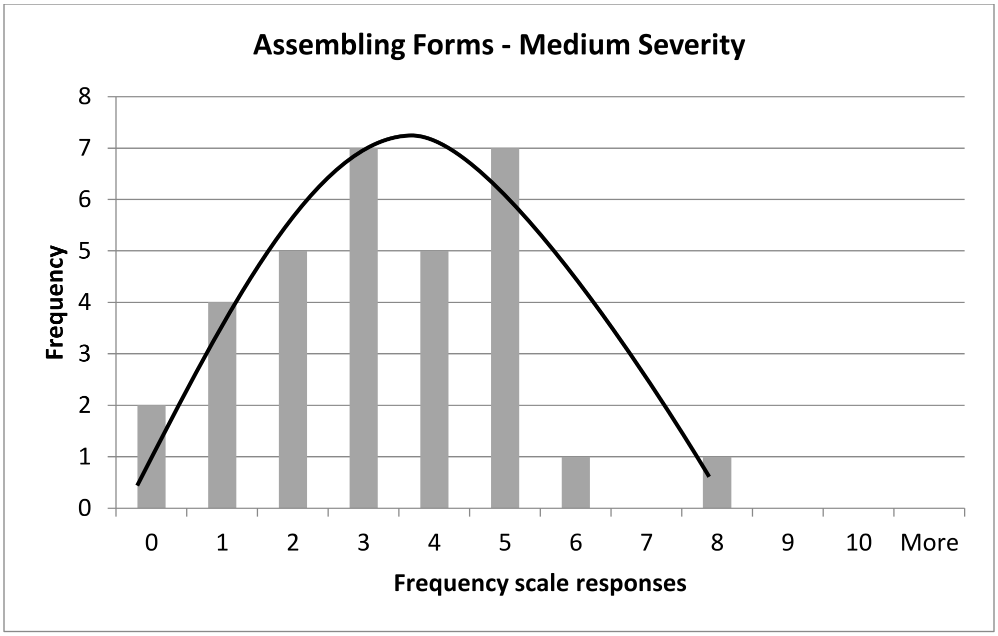
- Near Misses – Triangular Distribution
    - For the activity of dismantling and cleaning formwork or formwork components, the histogram is as follows:



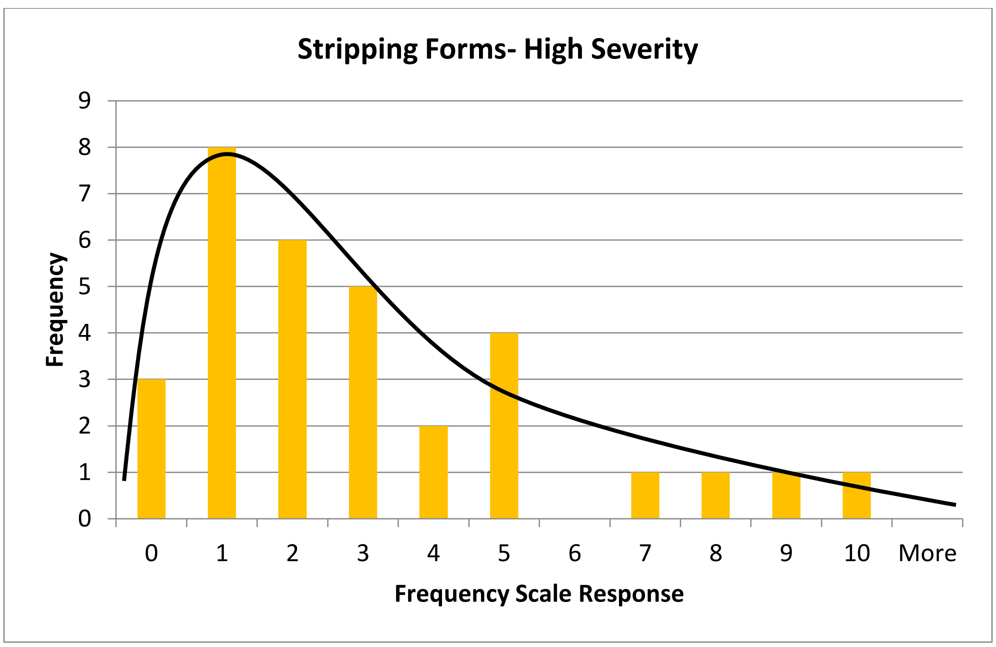
- Low Severity – Normal Distribution
  - For the activity of assembling forms, the histogram is as follows:



- Medium Severity – Normal Distribution
  - For the activity of assembling forms, the histogram is as follows:



- High Severity – Lognormal Distribution
    - For the activity of stripping forms, the histogram is as follows:



- Activity Exposure – Lognormal Distribution
    - For the activity of stacking prepared forms, the histogram is as follows:

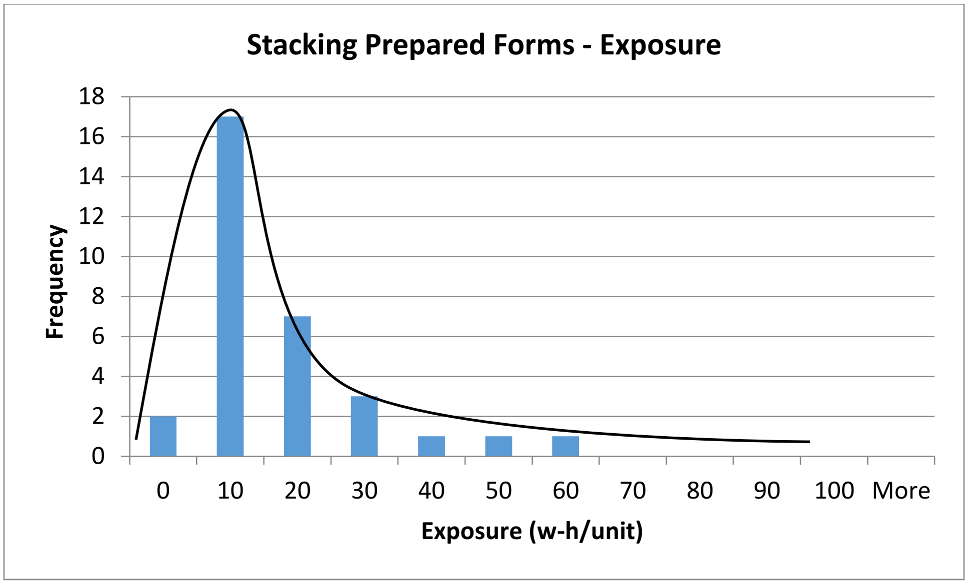


Table 5.4: Unit Risk and Cumulative Risk per Activity

Activity Performed	Unit Risk/activity (Severity/worker hour)	Cumulative Risk/activity (Severity/unit)
Stockpile	0.44	4.95
Preparation	0.62	17.25
Moving (Optional)	0.47	10.08
Assembling Forms	0.81	25.29
Stacking Prepared Forms	0.55	8.16
Moving	0.85	15.60
Erection/Placing Forms	1.07	39.15
Pouring Concrete/Curing	0.79	13.61
Stripping Forms	1.01	27.04
Move forms	0.63	9.43
Dismantling/ Cleaning Forms	0.56	9.52

Activity Performed	Unit Risk/activity (Severity/worker hour)	Cumulative Risk/activity (Severity/unit)
Move forms/ Form Components	0.66	10.47
Stack/ Stockpile Forms	0.68	10.42
TOTAL	**9.13**	**200.98**

The values for risk/activity in Table 5.4 are the expected or average values of risks. Figure 5.2 and Figure 5.3 show the probability densities of the unit risk and the total cumulative risk respectively, obtained after a simulation consisting of 10,000 iterations from @Risk.

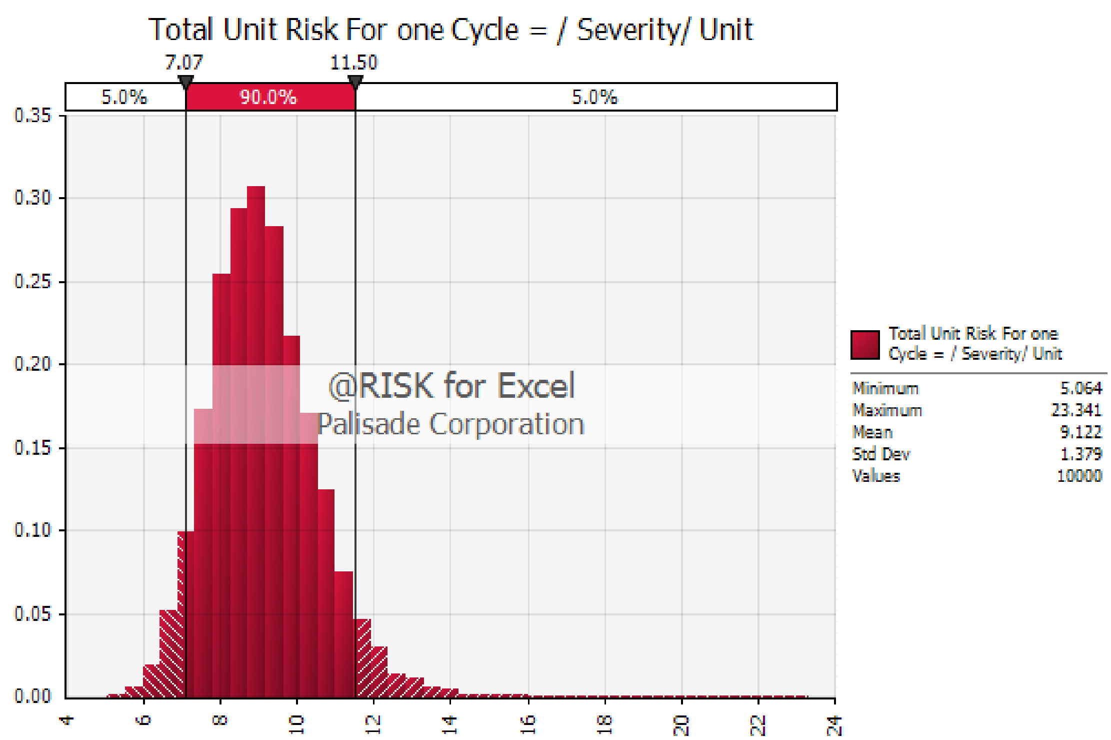


Figure 5.2: Probability Density of the Total Unit Risk

From Figure 5.2, it can be seen that there is a five percent probability that the total unit risk associated with one cycle of formwork use falls at 7.07, and there is a ninety five percent probability that the total unit risk associated with one cycle of formwork use falls at 11.5. These values reflect only the risk associated with performing each activity, and the amount of time the worker spends doing each activity is not factored into the unit risk.

Figure 5.3 shows that there is a five percent probability that the total cumulative risk associated with one cycle of formwork use falls at or below 118, and there is a ninety five percent probability that the total cumulative risk associated with one cycle of formwork use falls at 317 or lesser. The amount of time the worker is exposed to the risk associated with each activity is accounted for in the calculations for cumulative.

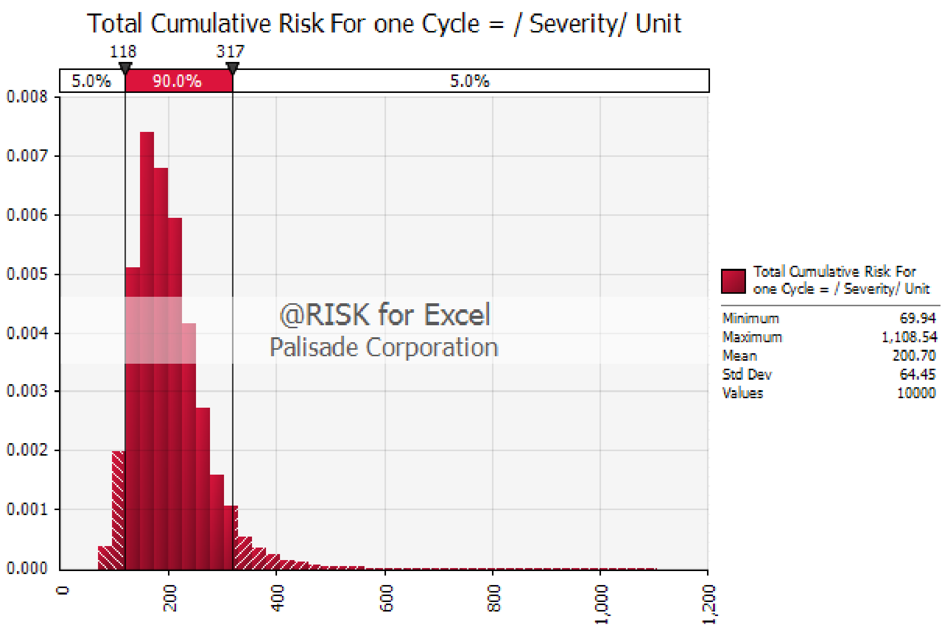


Figure 5.3: Probability Density of the Total Cumulative Risk

@Risk provides tornado plots with mapped regression coefficients that make understanding the sensitivity of the output variable to the different input variables easier. The best method of interpreting the sensitivity plot is that an increase of the input by one standard deviation causes a change in the output by the value indicated in the plot for the corresponding activity. For example, in Figure 5.4, if the standard deviation σ of the frequency values obtained for the activity of stripping forms in the high severity level increases by one σ, i.e. from σ to the value 2σ, the increase in the output value (in this case, total unit risk) will be 0.43 severity/unit.

Figure 5.4 and Figure 5.5 show the sensitivity of the total unit risk and the total cumulative risk, respectively, to the different activities at the 4 different severity levels.

The sensitivity analysis plot shows that a unit change in the value of unit risk calculated for the activity of stripping and high severity category brings about the maximum increase in the total unit risk. It is seen that the second and third most activities that cause the unit risk value to increase is moving forms/form components and the activity of moving prepared forms to the erection site, both in the high severity category. The fourth activity that affects the unit risk is stripping, in the near miss category. This can be interpreted to mean that the total unit risk posed to the worker in one formwork cycle is the highest for a high severity injury during the activity of stripping. Other activities that affect the total unit risk the most can be seen in Figure 5.4.

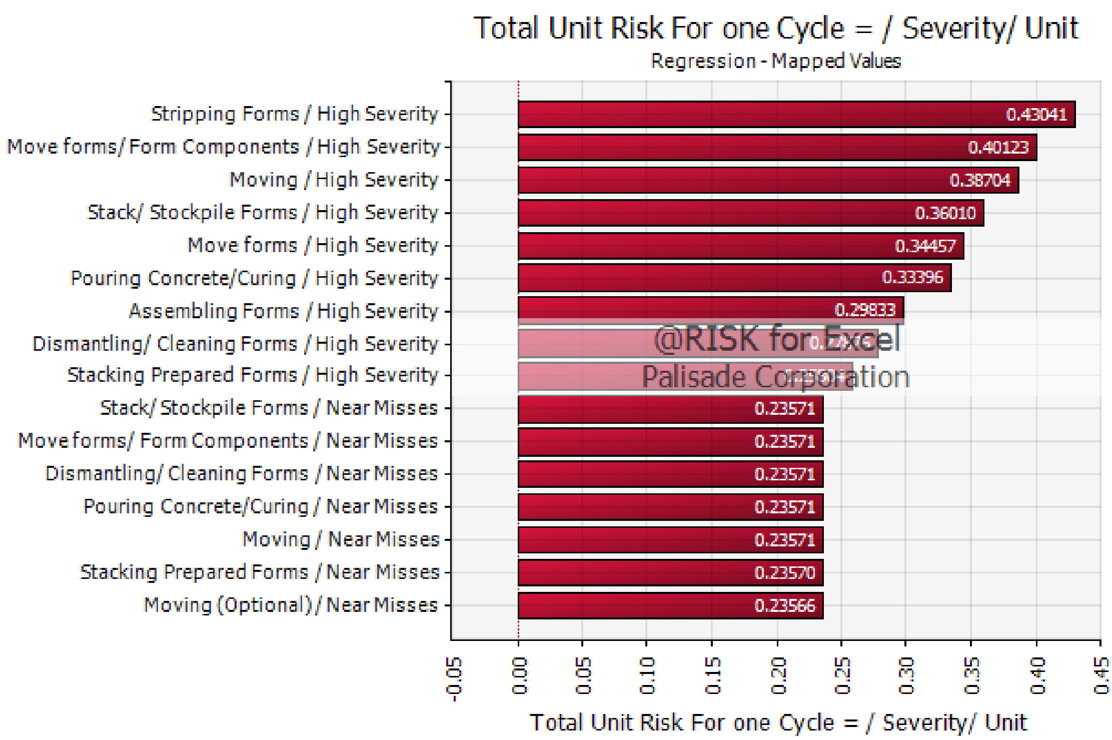


Figure 5.4: Sensitivity of the Total Unit Risk

The order of activities that affect the risk posed to the worker alters slightly when the exposure is also taken into account. The input that affects the total cumulative risk the most is the activity exposure for stripping formwork and that for the erection and placement of forms. The frequency of injury that affects the total cumulative risk the most is the activity of stripping forms again, for incidents of high severity. Further details of activities that affect the total cumulative risk can be found in Figure 5.5. Keeping this in mind, the probability density of the activities stripping forms, erecting forms, and moving forms/form components are obtained from @Risk. The probability densities of the cumulative risk associated with each of the activities mentioned are displayed in Figure 5.6, Figure 5.7, and Figure 5.8.

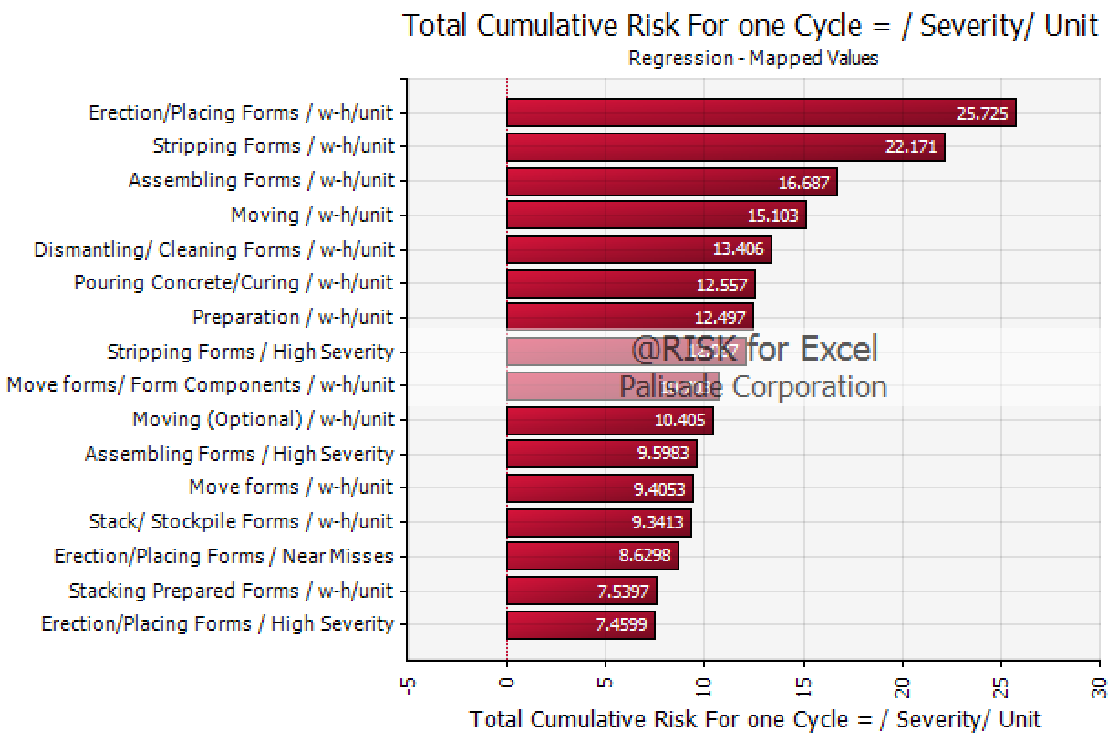


Figure 5.5: Sensitivity of the Total Cumulative Risk

The activity of stripping formwork is the activity that brings about the largest change in the total unit risk, as well as the activity that brings about the second largest change in total cumulative risk. From Figure 5.6, it can be seen that there is 5 percent probability that the cumulative risk value is as low as 4.7 for the stripping activity, whereas there is a 95 percent probability that the cumulative risk value for the same is as high as 74.4.

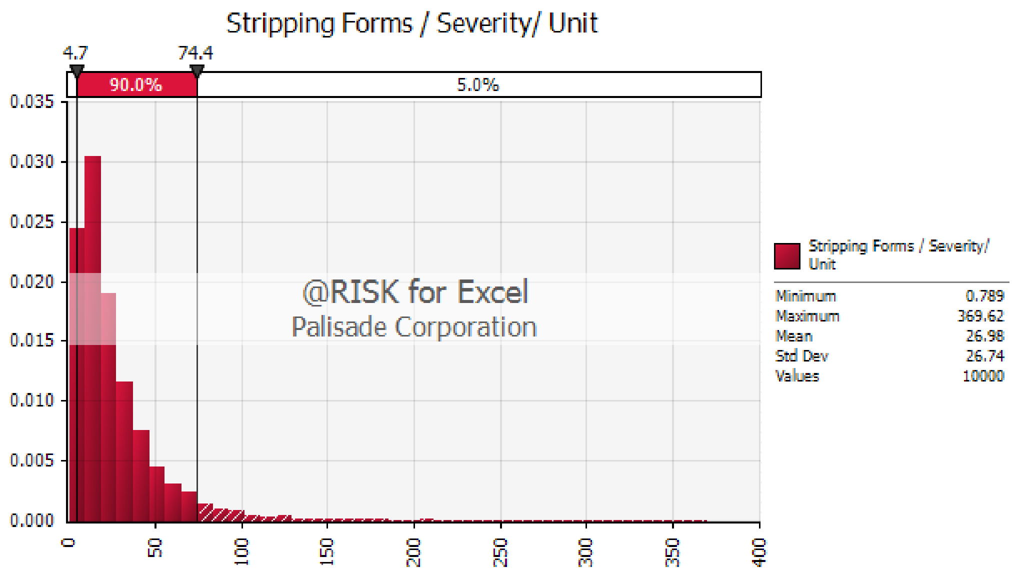


Figure 5.6: Probability Density, Cumulative Risk, Stripping Forms

The activity with the highest effect on Total Cumulative Risk is the activity of formwork erection, shown in Figure 5.7. There is 5 percent probability that the cumulative risk value is about 10 for the activity of erecting formwork, whereas there is a 95 percent probability that the cumulative risk value for the same is as high as 94. Similarly, for the activity of moving forms and/or form components, there is 5 percent probability that the cumulative risk value will be about 1.0, and 95 percent probability that the cumulative risk value is 33.6. The probability density distribution of the total cumulative risk associated with the activity 'Move forms/ Form components' can be seen in Figure 5.8.

It is also worth noting that the risk values here are based on the respondents' perception of their exposure to risk, and the type of incidents that may occur at various frequencies.

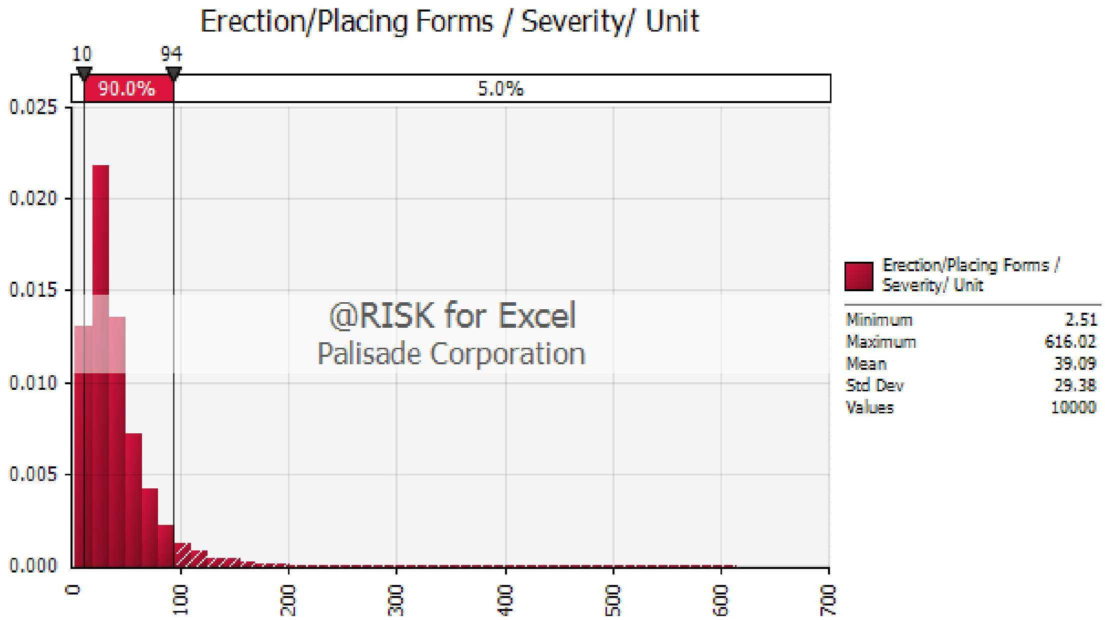


Figure 5.7: Probability Density for Cumulative Risk, Erecting Forms

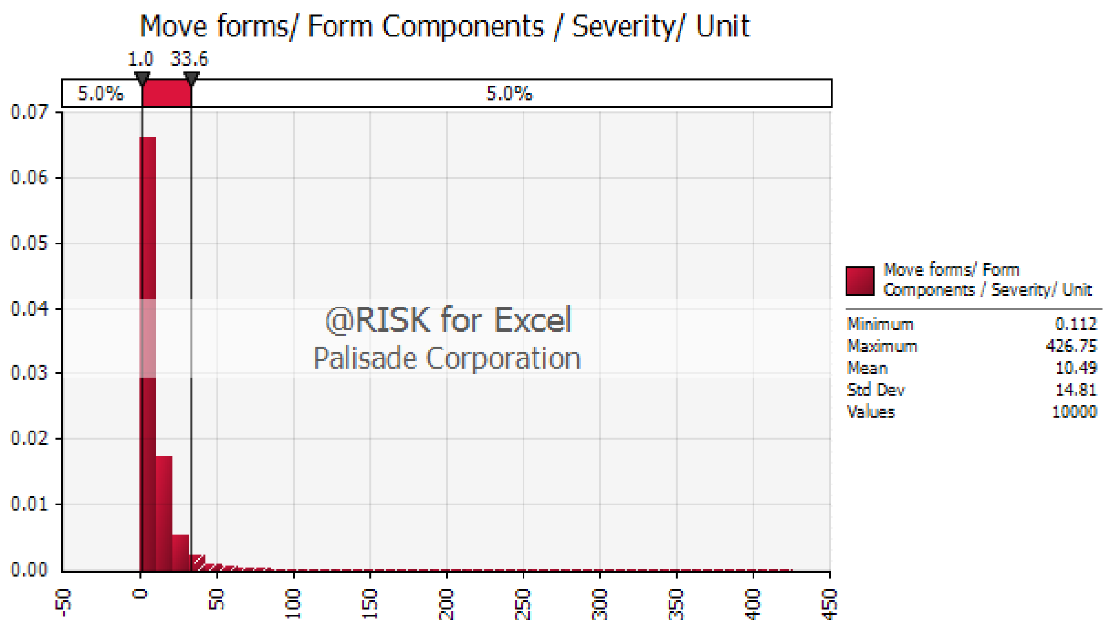


Figure 5.8: Probability Density of Cumulative Risk, Moving Forms/ Form components

5.2.1. COMPARISON WITH OSHA CASE STUDY RESULTS

The statistics from the OSHA case studies do not match the order obtained from the @Risk simulations. According to the OSHA statistics, the largest number of incidents occurred during the activity of pouring of concrete, followed by the activities of erection of forms and stripping forms. The reasons for this could be several:

i. OSHA does not classify incidents according to severity levels, and due to a lack of sufficient detail in the incident summary, an incident might have been assigned to a different severity level.
ii. The number of incidents may not be accurate, as most near miss incidents and low severity incidents do not meet the criteria for an OSHA recordable incident.
iii. No distinction is made between horizontal and vertical formwork use in the OSHA case summaries.
iv. The data from the OSHA case summaries span chronologically from 1984 to 2012. Many significant changes in safety requirements, practices and law have occurred in this period. Hence, potential hazards that could have caused incidents are minimal, or altered in the current work environment during the use of formwork.
v. The risk values obtained from @Risk are based on the perceptions and opinions of workers in the industry. The actual risk posed to the workers may be different from the perceived risk.

5.3. RELIABILITY ASSESSMENT

5.3.1. ASSUMPTIONS

To calculate the reliability index β and probability of failure (P_f) using methods described in Chapter 3, it is necessary to calculate the mean and standard deviation of the load demand for the formwork used at each project site. These calculations were performed for Projects 1 and 3, from which samples with established numbers of uses were obtained. Samples from Project 2 are not included as the number of uses the samples were subjected to could not be determined with a high degree of certainty on this project.

In the absence of measured onsite loads, calculation of lateral pressure has to account for several factors such as mix design, rate of placement, and temperature. Hence, necessary information about these factors were obtained from the Project Engineers onsite. For Project 1, the average rate of placement of concrete based on available information was 20 cubic yards/hour (cy/hr), which, upon conversion, meant that the rate of placement varied from 14 ft/hr to 17 ft/hr, depending on the thickness and height of the specific wall. All wall forms had the same spacing of joists, and the forms were used interchangeably depending on walls of different dimensions. Hence, the maximum height and thickness of wall were considered as design values, and equation (2.1) was deemed appropriate for use.

The mean unit weight of concrete was reported to be 142 pounds per cubic feet (pcf) from the mix design, and the aggregate used was 3/8 inch. Based on the aggregate size, the COV reported in Ellingwood et al (1980) was used. The demand parameters for reliability assessment to be used in equation (3.4) - were calculated based on the mean μ_γ and standard deviation σ_γ of the unit weight.

Calculation of parameters for samples from Project 3 was more challenging, as the plywood tested was obtained from bulkheads, which are the forms used as stoppers at the end of wall forms. Although these are used for wall forms, the dimensions are more like that of a column, and hence Equations (2.1) and (2.2) were considered for design purposes. Since the wall height is 15 ft, and the placement of concrete for the entire wall took place at the same time with no interruptions, Equation (2.1) was deemed appropriate for estimating the lateral pressure demand The demand parameters for reliability assessment - mean of demand ($\mu_{Q)}$ and standard deviation of demand ($\sigma_{Q)}$ were calculated based on these values.

After obtaining these values, the reliability index and the probability of failure for each use of formwork tested in Projects 1 and 3 were calculated and adjusted using the Equations (3.4) and (3.5) for various conditions and levels of uncertainty. The obtained values of reliability indices and probabilities of failure are presented in the next subsection.

5.3.2. RESULTS

The reliability index (β) and the probability of failure (P_f) of the formwork panels observed in projects 1 and 3 were calculated using the equations presented in Chapter 3, and are presented in this section.

Table 5.5 shows the values of β for bending (β_1) and for shear (β_2). The test data obtained had a few outliers, which were much higher or lower than the average values. To assess if the removal of outliers has any effect on the reliability indices, the indices are calculated with the outliers removed from the data set (β_1' and β_2' in the Tables) also. The corresponding probability of failure can also be found in the columns adjacent to each column of β_1, β_2, and β_1'and β_2'. From these calculations, all samples from Project 3 and Project 1 show low to moderate probabilities of failure. The degree of uncertainty due to the large range exhibited in the boxplots in Chapter 4 also has an effect on the β and the P_f values.

Table 5.5 β and Pf for all tested samples, with and without extreme outliers in the test data

	No. of Uses	**Bending, with outliers**		**Bending, without outliers**		**Shear, with outliers**		**Shear, without outliers**	
		β_1	P_f	β_1'	P_f	β_2	P_f	β_2'	P_f
Project 3 Samples	**0 uses**	3.11	0.1%	2.42	0.8%	3.82	0.0%	5.74	0.0%
	1 uses	2.27	1.2%	0.96	16.9%	13.14	0.0%	14.95	0.0%
	2 uses	1.60	5.5%	0.46	32.3%	4.53	0.0%	8.30	0.0%
Project 1 Samples	**0 uses**	1.73	4.2%	0.59	27.8%	13.34	0.0%	16.68	0.0%
	2 uses	1.19	11.8%	0.38	35.1%	10.87	0.0%	14.60	0.0%
	5 uses	3.63	0.0%	1.29	9.8%	10.18	0.0%	11.56	0.0%
	8 uses	0.85	19.9%	0.58	28.2%	7.82	0.0%	10.83	0.0%
	11 uses	1.82	3.5%	0.65	25.7%	7.74	0.0%	7.89	0.0%
	14 uses	2.34	1.0%	0.81	20.9%	9.27	0.0%	10.00	0.0%

The P_f values seen in Table 5.5 for both shear and bending capacities are consistent with the onsite observations as no formwork failure was observed at either project. The high probabilities of failure values observed in some cases could be attributed to the conservative estimate of design load demand obtained using equation (2.1). Hence, reliability indices were calculated for Project 3 and Project 1 with three levels of uncertainty: COV = 10%, 30% and 50%. The COV values are obtained following general uncertainty design tables proposed in the *FEMA P695: Quantification of Building Seismic Performance Factors* (ATC, 2009) document. The values calculated can be seen in Table 5.6 and Table 5.7 for Project 3 and Project 1 respectively. It is worth noting that no additional bias was considered.

There is the possibility of additional variability in the design model for Project 3, as the tested samples were obtained from bulkhead forms, and the design load demand was calculated using equation (2.1), assuming that loading is similar to that for column forms. It can be seen that as the uncertainty increases, the probabilities of failure also increase for β_1, β_2, β_1' and β_2'.

Table 5.6: β and Pf for Project 3 samples, with assumed standard deviation for demand

	No. of Uses	Bending, with outliers		Bending, without outliers		Shear, with outliers		Shear, without outliers	
		β_1	P_f	β_1'	P_f	β_2	P_f	β_2'	P_f
	COV = 10%								
Project 3 Samples	**0 uses**	2.91	0.2%	2.01	2.2%	4.52	0.0%	6.66	0.0%
	1 uses	1.48	6.9%	1.06	14.5%	14.29	0.0%	16.05	0.0%
	2 uses	0.88	19.0%	0.76	22.4%	5.21	0.0%	9.45	0.0%
	COV = 30%								
Project 3 Samples	**0 uses**	2.26	1.2%	1.70	4.5%	3.91	0.0%	5.20	0.0%
	1 uses	1.15	12.5%	0.86	19.4%	8.39	0.0%	8.70	0.0%
	2 uses	0.74	22.9%	0.68	24.9%	4.52	0.0%	6.31	0.0%
	COV = 50%								
Project 3 Samples	**0 uses**	1.69	4.5%	1.35	8.8%	3.18	0.1%	3.89	0.0%
	1 uses	0.86	19.5%	0.67	25.2%	5.52	0.0%	5.60	0.0%
	2 uses	0.59	27.7%	0.57	28.4%	3.70	0.0%	4.34	0.0%

Table 5.7: β and Pf for Project 1 samples, with assumed standard deviation for demand

	No. of Uses	Bending, with outliers		Bending, without outliers		Shear, with outliers		Shear, without outliers	
		β_1	P_f	β_1'	P_f	β_2	P_f	β_2'	P_f
		COV = 10%							
Project 1 Samples	**0 uses**	1.73	4.2%	1.62	5.2%	12.41	0.0%	15.01	0.0%
	2 uses	1.16	12.2%	1.14	12.7%	10.22	0.0%	13.17	0.0%
	5 uses	3.48	0.0%	3.51	0.0%	9.78	0.0%	11.01	0.0%
	8 uses	1.25	10.5%	0.83	20.3%	7.64	0.0%	10.39	0.0%
	11 uses	1.91	2.8%	1.74	4.1%	7.41	0.0%	7.56	0.0%
	14 uses	2.95	0.2%	2.23	1.3%	8.79	0.0%	9.42	0.0%
		COV = 30%							
Project 1 Samples	**0 uses**	1.10	13.5%	1.04	14.9%	7.61	0.0%	8.19	0.0%
	2 uses	0.77	22.2%	0.83	20.2%	6.54	0.0%	7.25	0.0%
	5 uses	2.57	0.5%	2.62	0.4%	7.02	0.0%	7.50	0.0%
	8 uses	0.98	16.3%	0.70	24.2%	6.11	0.0%	7.36	0.0%
	11 uses	1.22	11.2%	1.24	10.7%	5.24	0.0%	5.33	0.0%
	14 uses	1.59	5.5%	1.53	6.3%	5.88	0.0%	6.11	0.0%
		COV = 50%							

	No. of Uses	Bending, with outliers		Bending, without outliers		Shear, with outliers		Shear, without outliers	
		β_1	P_f	β_1'	P_f	β_2	P_f	β_2'	P_f
Project 1 Samples	**0 uses**	0.75	22.7%	0.71	24.0%	5.07	0.0%	5.28	0.0%
	2 uses	0.52	30.0%	0.60	27.5%	4.43	0.0%	4.69	0.0%
	5 uses	1.86	3.1%	1.91	2.8%	5.00	0.0%	5.21	0.0%
	8 uses	0.74	23.0%	0.55	29.0%	4.65	0.0%	5.21	0.0%
	11 uses	0.82	20.5%	0.88	18.9%	3.71	0.0%	3.76	0.0%
	14 uses	1.03	15.3%	1.07	14.2%	4.05	0.0%	4.16	0.0%

CHAPTER 6. CONCLUSION

The conclusions drawn from the obtained results and discussion, and the extent to which the primary objectives set forth in Chapter 3 have been achieved are presented in this section.

Primary objective #1 was to map the typical use cycle of vertical timber formwork. This was achieved by establishing a sequence of activities that constitute one formwork use cycle, and validated by observing formwork use cycles at three different projects. A clear picture of the different formwork activities being employed on various construction sites was obtained, leading to the development of a mapped workflow of the formwork use cycle. The general mapped workflow can be applied to any project by adjusting the workflow by eliminating the unnecessary steps. This can help in identifying and keeping track of the number of uses, as well as monitoring the degradation of formwork. It can also be used as a value stream map for identifying improvements in safety and productivity.

Primary objective #2 was to identify the primary factors contributing to risks associated with use and re-use of formwork and evaluate the risks the workers are exposed to while carrying out various activities in the formwork cycle. The risks posed to the workers were quantified and evaluated using the safety survey, and the results of the survey were used as inputs to a risk model. This helped in identifying stripping and erection activities as those activities that have the highest impact on the overall risk associated with formwork use and reuse, taking into account the frequency of injury at different levels as well as the exposure of the worker to the risk.

Primary objective #3 was to calculate the reliability associated with the use and reuse of formwork, so as to ascertain the ability of the monitored formwork to fulfil its purpose. The preliminary reliability calculations shown in Chapter 5 reveal that the actual capacity of the formwork component (plyform) obtained from testing is comparable to the estimated lateral load demand on the formwork. Possible reasons for variations in these calculations are discussed in the next subsection.

The ultimate goal of the study was to obtain a mapped formwork use cycle, with a measured loss in capacity per use. The loss of capacity per use was to be linked to an increase in the quantitative risk values – the total unit risk and the total cumulative risk - to the workers handling formwork. The reduction in capacity per use would also be an indicator of increasing probabilities of failure due to reduction in the mean capacity value and larger uncertainty, i.e., standard deviation, as number of uses increases. Only a moderate degradation was obtained from testing the samples from Project 1 and Project 3 and it was hypothesized that a larger of number of uses would be needed to see significant/ larger degradation in strength. Thus, the mapped formwork use cycle and the risk model assume no degradation. A degradation trend obtained from further research can be incorporated into both the formwork use cycle as well as to the risk model so as to obtain a formwork model with risk and reliability values that account for degradation.

As explained in detail in Chapter 4, the mixed trend observed in testing could be attributed to the inherent variability of the material itself. Most test specimens were prepared from just one or two samples per use due to limited availability of samples per number of uses. Hence a true assessment of deterioration in strength due the number of uses requires samples from additional sites, which were not possible. Additionally, the estimation of design demand for the formwork may be different from the actual load demand on the formwork, as the value estimated by equation (2.1) is conservative. Hence, it is suggested that the actual load onsite is measured in future work.

6.1. CHALLENGES FOUND IN THIS STUDY

There were several challenges encountered in this study, namely:

i. The sample population for both the projects monitored as well as the respondents to the questionnaire and safety survey is limited only to a relatively small region in the United States, namely Northwest Oregon. Validation of the obtained results may have to be done with inputs from a larger population to ensure applicability to the general construction industry. This limitation affects the risk assessment and the mapped workflow of the general formwork use cycle.

ii. The risk values obtained depend on the risk perception of each respondent. This may depend on the risk tolerance of the individual, the amount of importance afforded to jobsite safety, and the overall safety culture of the employer and the respondent. These may also vary with the geographical region.

iii. Although deterioration was observed, there is no established method to quantitatively assess and monitor deterioration to formwork panels and formwork components. This makes the assessment of risks associated with deterioration of formwork with each use difficult.

iv. The deterioration observed on formwork will increase as the number of reuses increase, resulting in increased risk to the workers. However, this has not been factored into the formwork model as a clear trend in deterioration was not obtained.

v. The test methods adopted from ASTM 3043 and ASTM 2718 allow for further variability in the test results due to variations in sample dimensions. Different test methods assessing Modulus of Rigidity (MOR) rather than maximum load could provide results that are not affected by the variability in sample dimensions.

6.2. SCOPE FOR FURTHER STUDY

This study can be viewed as a preliminary study, aimed towards understanding and quantifying the deterioration of formwork with use and reuse as well as identifying the risks associated with use and reuse of formwork. The following recommendations for further investigations are proposed based on the conclusions and limitations of this study:

i. It is important to be able to quantify the actual deterioration of formwork on site in addition to loss of capacity by testing, and factor the results into a similar risk model. This model can emulate a realistic formwork use cycle, where the number of uses is limited, and the risks assigned would increase as the number of uses increase.

ii. Validation of the research study by sampling over a wider population will increase the applicability of the conclusions of this study to the construction industry as a whole.

iii. The testing of formwork components can be performed using specimens prepared from samples obtained from different panels with same number of uses, or use samples that have been used in a controlled environment so as to reduce the variability further.

iv. An accurate estimation of the design demand can make the calculations for the reliability indices and probabilities of failure closer to the true probability values. This can be done by measuring the actual loads on the formwork while it is being used.

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APPENDIX

APPENDIX – I A: FORMWORK QUESTIONNAIRE

Interview questions for Construction Sites/Firms-

(Please tick all options that apply)

1. **General:**
   a. Identify various components that constitute formwork at this project site:
      - ☐ Component 1 -______________________________________
      - ☐ Component 2 -______________________________________
      - ☐ Component 3 -______________________________________
      - ☐ Component 4 -______________________________________
      - ☐ Connections -______________________________________

   b. What is the formwork source?
      ☐ Self-owned ☐ Assembled at jobsite ☐ Assembled off-site ☐ Rented
      ☐ Others(please specify) ____

   c. Other than the design loads (ASCE 37-02), what other loads (including environmental) are typically considered for formwork use?
      ☐ Rain ☐ Snow ☐ Manufacturers' Specifications ☐ Embedments
      ☐ Worker load ☐ Others(please specify)____________________________

   d. What are the most frequent problems associated with wall/column (basically vertical) formwork?
      ☐ Out-of-plumb ☐ Warping ☐ Cracks ☐ Surface Finish ☐ Overload(eg-higher rate of pour) ☐ Others(please specify) ____________________________________

   e. Formwork condition-
      i. What condition makes the formwork acceptable for this project?
         ☐ Unused ☐ Used but in reasonable condition
         ☐ Others (please specify) ____
      ii. If used but in reasonable condition, how is the condition of formwork assessed?

         ____

2. **Stockpiling/Storage:**
   a. How is the formwork stored?
      ☐ Exposed ☐ Covered ☐Indoors ☐Outdoors ☐ On ground ☐ Platforms
      ☐ Others (please specify) ____

   b. In case of any moderate to severe weather change (rains, snow), are any changes made to the formwork stockpile/storage? Is there any seasonal change?

      ____

   c. What other factors determine how the formwork is stockpiled/stored?

      ____

   d. How does the way the formwork is stockpiled influence the formwork performance? Is this assessment performed? How?

      ____

3. **Assembly of formwork:**
   a. Could you describe the formwork erection process?(specifically, vertical formwork)

      ____
      ____

b. Other than design differences, are there differences in the assembly process of different vertical formwork?(columns, walls)

____

c. Other than design differences, are there differences in the erection process of different vertical formwork?(columns, walls)

____

d. What connectors are typically used, and how are they installed?
□ Mechanically driven □Installed by hand
□ Others(please specify) ____

4. Pouring of Concrete:

a. Before pouring concrete:

i. Is there a typical timeframe for how long the formwork stays in place?
(_____ days)

ii. Are there any external impacts on the formwork in the meantime?
□ Wind □ Personnel Climbing on it □Equipment loads
□Others(Please specify)

b. Is there a typical timeframe for how long the formwork stays in place after pouring concrete?
(______ days)

c. Seasonal Variations-

i. Does the season during which the work is done affect the time after pouring before the formwork is removed? (Yes/no)

ii. If so, how?
- Time increases by ____/____/____/____ days in Summer/Spring/Fall/Winter due to
____
- Time decreases by ____/____/____/____ days in Summer/Spring/Fall/Winter due to
____

5. Transportation & Removal:

a. How is the formwork removed?
□By Hand □Using Cranes/Forklifts □Others(Please specify)

b. How is the formwork moved around from place-to-place?
Within the site- ______________________________________
From site to site- ______________________________________

6. Degradation & Re-use:

a. Observations:

i. What kind of degradation can be most commonly observed?
□ Edges/Corners □Faces □ Structural Cracks
□ Others(please specify)____

ii. After how many uses?
□ Edges/Corners - ________ times □Faces - ________ times
□ Structural Cracks - ________ times
□ Others(please specify)____

b. How many times is a particular component of formwork used before it is judged to be unfit for re-use?

□ Component 1 - ________ times □Component 2 - ________ times

□ Component 3 - ________ times □Component 4 - ________ times

□ Connections - ________ times

c. What methods are used for this assessment?

□ Visual Inspection □Others(please Specify)____

d. What is the Deciding factor that makes you say that a particular formwork cannot be re-used?

____

e. Manufacturer's Guidelines:

i. Are there any guidelines/suggestions from the manufacturer on the number of re-uses?

□ Yes □ No

ii. Are these taken into account?

□ Yes □ No

7. Failure & Injuries:

a. What are the typical causes of formwork failure?

□ Failure of ties/connections □ Bending □ Deflection □ Shear □Blowouts

□Others(Please specify)____

b. Have any cases of formwork failure occurred on this project? If so, what was the cause and impact?

____

c. Have there been any minor worker injuries associated with formwork on this project?

____

d. If yes, how many?

____

8. On a scale of 1 to 5, rate the impact of the following factors on the use and re-use of formwork:

Factors Impacting the lifecycle of formwork	Very large Impact	Large Impact	Medium Impact	Some Impact	Nominal Impact	No Impact
	(5)	(4)	(3)	(2)	(1)	(0)
Construction Loading						
Climbing up						
Warping						
Cracks						
Surface Damage						
Storage conditions						
Assembly						
Design						
Connections						
Ties						
Removal						

Factors Impacting the lifecycle of formwork	Very large Impact	Large Impact	Medium Impact	Some Impact	Nominal Impact	No Impact
	(5)	(4)	(3)	(2)	(1)	(0)
Increase/decrease in temperature						
Increase/decrease in humidity						
Accidental impact						
____________						
____________						

(Please add in any other relevant factor in the last 2 rows)

APPENDIX I-A: SUMMARY OF RESPONSES FROM FORMWORK QUESTIONNAIRE

Sl. no: of Respondents	1	2	3	4	5	6	7	8	9	10
Section 1. General-										
a. Components:										
Component 1	Plywood	ties	Gang form	Gang form	Gang form	Gang forms	Wood/ Snap ties	plywood	Plywood facing	2x members, steel stakes
Component 2	MDO Plywood	Braces	BFD Clamp		BFD Clamp	Misc. hardware	Camlocks	2x4	wood forms	.75" plywood, 2x4, camlocks, snap ties
Component 3	MDO Plywood	Misc. Hardware	Tar whaler	BFD's, form ties & wing nuts	Tar whaler	Plywood	plywood	Chamfer	shafts	2x members, tapers, tilt brackets
Component 4	Steel Gang Forms	Lumber	Tie rod & wing nut	Tar whaler	Tie rod and self form	Snap ties	Steel/Tar whaler/ BFD	Stakes	pylons	
Connections	Nails, Screws	nails, Screws, stakes, Clamps	Pipe braces					Clamps	bolts, clamps	
b. Formwork Source:										
Self-owned	**X**	x	x	x		x	x		x	x

Sl. no: of Respondents	1	2	3	4	5	6	7	8	9	10
Section 1. General-										
Assembled on-site		x	x	x	x	x	x	x		x
Assembled off-site									x	
Rented									x	
Others									preassembled	
c. Other loads:										
Rain										x
Snow										
Manufacturer's Specifications	**X**	x			x		x	x		
Embedments										
Worker load			x	x		x				
Others	Desired Finish/look	Material Loads				Access, Availability			Engineered Loads	
d. Frequent Problems:										
Out-of-plumb		x		x	x	x		x	x	
Warping						x			x	
Cracks						x				
Surface Finish	X	x	x	x	x	x	x	x		x
Overload	X			x						x
Others		How straight the wall is							Fitting	
e. Formwork Condition:										
i. Acceptable Condition-										

Sl. no: of Respondents	1	2	3	4	5	6	7	8	9	10
Section 1. General-										
Unused					x	x	x		x	x
Used, reasonable Condition	X	x	x	x	x	x	x	x	x	
Others										
ii. Method of Assessment-	Visual Inspection	No. of holes, Squareness, structural integrity	Surface & structural damage	Broken and/or bent	assessed by workers	Face & Edge conditions	assessed by workers	Look for holes, breaks, divits	Visual Inspection	

Sl. no: of Respondents	11	12	13	14	18	19	20	21	22	23
Section 1. General-										
a. Components:										
Component 1	.75" plywood	steel stakes	2x members	Steel Facades		Form plywood	Dimensional lumber	2x4's	Plywood, 0.75'' & 1.125''	Plywood 1.125''
Component 2	2x4 whalers	Dimensional lumber	Stakes, angle brackets	4x6 whalers		Dimension al lumber	Plywood	plywood forms	2x4's	Plywood, 0.75''

Sl. no: of Respondents	11	12	13	14	18	19	20	21	22	23
Section 1. General-										
Component 3	2x12	plywood	nails, screws	Steel C-channels		Snap ties	Steel stakes, turnbuckles	steel stakes	Steel Stakes, 3' o.c.	2x4's
Component 4	steel stakes	Hardware		Plywood Skin (inner face)		John A Brackets, hairpin, strapping		alisply systems	Banding, 4' o.c.	Banding 3/4'',1/2''
Connections	Camlocks (John A Brackets)	nails		She-bolts		Duplex nails	Snap ties	Pencil rods, snap ties @ 2' o.c.	16/8 penny nails for 2x's & banding	Nails, Screws
b. Formwork Source:										
Self-owned	x	x	x	x	x	x		x	x	x
Assembled on-site	x	x	x	x	x	x	x	x	x	x
Assembled off-site		x							x	
Rented	x	x						x		x
Others									Purchased	
c. Other loads:										
Rain	x	x		x					x	
Snow	x	x							x	
Manufacturer's Specifications	x	x	x					x	x	
Embedments	x	x	x		x	x	x	x	x	

Sl. no: of Respondents	11	12	13	14	18	19	20	21	22	23
Section 1. General-										
Worker load	x	x				x	x	x	x	x
Others				Wind, Deflection (l/1000)						
d. Frequent Problems:										
Out-of-plumb	x	x		x		x	x		x	x
Warping	x			x					x	x
Cracks									x	x
Surface Finish	x	x	x			x	x	x	x	x
Overload	x		x			x	x	x	x	x
Others			Vibration	Tolerances	Finished Product Quality	Over consolidation/ vibration				
e. Formwork Condition:										
i. Acceptable Condition-										
Unused	x			x			x		x	x
Used, reasonable Condition	x	x	x	x	x, surface blemishes	x	x	x	x	x
Others					Structural integrity		depends on project			
ii. Method of Assessment-	Not warped/split/ veined/ covered in concrete	visual inspection	no warping & cracking	scraped & oiled, no holes/burrs/concrete	Concrete foreman assesses it	straight/ clean	final finish requirement	surface condtns, smoothness, no chips	Visual Inspection, defects such as surface damage	How many times it has been already used

Sl. no: of Respondents	1	2	3	4	5	6	7	8	9	10
Section 2. Stockpiling/storage-										
a. Method of Storage:										
Exposed	x	x	x		x	x	x	x	x	
Covered		x								x
Indoors					x					
Outdoors	x	x	x	x	x	x	x	x	x	
On ground	x	x	x			x	x			
Platforms/ Dunnage		x					x	x	x	x
Others		depends on forms								
b. Changes in storage methods due to weather/season change:	no	Possibly, generally no	none	outside	no	no	no	no, things damaged by weather stored covered on dunnage	no	covered to prevent swelling/ shrinking
c. Other factors influencing storage:	Time, money, Necessity	Order of use, Location of use	type of material	weight and height	Size of Concrete work	Type of formwork	Size of Jobsite	size, shape, weight	Space	jobsite logistics

Sl. no: of Respondents	1	2	3	4	5	6	7	8	9	10
Section 2. Stockpiling/storage-										
d. Influence of Storage Methods on performance:	not assessed, but influences majorly	storing like sizes/ types increases efficiency	has to be stored flat to prevent warping	Can't let the forms bow or get mud on surface	Rust on steel forms	even stacking can prevent warping	Rust on Steel forms	correct stockpiling makeswork easier and faster	sequential layout increases efficiency and speed of work	banding & covering forms prevent defects

Sl. no: of Respondents	11	12	13	14	18	19	20	21	22	23
Section 2. Stockpiling/storage-										
a. Method of Storage:										
Exposed	x			x			x	x	x	x
Covered		x			x	x	x		x	x
Indoors			x			x			x	
Outdoors	x	x			x	x	x	x	x	x
On ground				x				x	x	x
Platforms/ Dunnage	x	x	x	x	x	x	x		x	x
Others	Access to forklifts							no surface contact	Lath used in btwn layers	

Sl. no: of Respondents	11	12	13	14	18	19	20	21	22	23
Section 2. Stockpiling/storage-										
b. Changes in storage methods due to weather/season change:	Covered for snow/ heavy rain	no	keep as dry and protected as possible	no	covered during rain, kept out of long periods of sunshine to prevent cracking	covered and extra oiling during rain/heavy snow	Covered to prevent warping	tied off in bad weather	Summer- stacked w/o platforms/laths, Winter- Stacked w/ platforms/lath in btwn	Not so much
c. Other factors influencing storage:	Banding for long term storage	Availability of Space	stacked to prevent warping	Space- availability	labor dollars	straight racks	material type and size	bands	Thickness, Size, structural integrity	Duration of time stored
d. Influence of Storage Methods on performance:	banding and covering reduce damage in long term storage	Neat stockpiling	Cleanly stacked	load path during long-term sorage(>3 months)	Not sure	level and plumb storage	depends on duration of storage	no, form lines may make a difference	Forms stacked w/ equal platforms at a minimum of 2' o.c., to prevent warp	Heat/sun exposure affects lumber

Sl. no: of Respondents	1	2	3	4	5	6	7	8	9	10
Section 3. Assembly-										
a. Description of Erection Process:	Clean, layout, snap lines, plate, stand plywood, install, walers, strongbacks, plumb+line, shoot grade, install chamfer, blockouts, reveals, etc. Install button up panels, then hardware, walers, strongbacks, bulkheads, plumb & line.	Gang forms = layout, set forms, pour, strip and reset. Handset = layout, set forms, pour, strip, clean-up, recycle, everything that is re-usable.	Plywood is drilled and stood, snap ties are installed with camlocks, whalers and braces are installed. Closing plywood is installed in the same fashion.	hand-set walls	Pour concrete & lay out walls	Layout concrete, set first side of forms, install any interna pipes (i.e., snap ties & coil rod), set button up side, brace & line & reinforce entire pour	Pour footing, layout wall line, roto hammer plate down, stand plywood, put on ties, camcocks, walers, strong backs, braces, line wall, button up other side, pour.	Stand sheets, rap with 2X4	Cranes, Pre-fabricated panels, moved in place by cranes	Vertical forms are assembled on the footing first. One side is set then steel is erected. Then close-up side is installed.
b. Diff. between wall/column assembly process?:	yes, absolutely	Minor. Nothing major	yes	yes	most of those, the installation, its the same	no	yes, wood to steel are different.	yes	generally same	Gang forms may be assembled in sections verses handset that is assembled piece by piece.

Sl. no: of Respondents	1	2	3	4	5	6	7	8	9	10
Section 3. Assembly-										
c. Diff. between wall/column erection process?:	yes	sequences of rebar & formwork could affect size or portion gang set.	yes	yes		no	yes, wood you can hand pack, steel forms need forklift or crane.	yes	N/A	Gang forms generally are set by crane. Handset is erected in place.
d. Connections Used-										
Mechanically driven		x							x	
Installed by hand	x	x	x	x	x	x	x	x	x	x
Others		nails, screws, stakes, clamps					rotohammer, screw gun			

Sl. no: of Respondents	11	12	13	14	18	19	20	21	22	23
Section 3. Assembly-										
a. Description of Erection Process:	Layout, template, erect, plumb & line top (allone side) install reinforcement - then install other side.	erected by hand	Build form, add rebar, nail form together, wrap forms with 2X4s, brace form 2X4 to the ground with metal stakes.	set one face, install rebar curtain, embedmen ts, adjust, set inside face, insert she-bolts, access decks placed, concrete poured	N/A	string lines, stake points, bring to elevation and nail forms	estalish gridlines, install concrete stakes, 2x's nailed in	Each type's different - footing, snap ties for elevator shaft, Alisply forms	Secure the base,fasten stakes to concrete, set forms, plumb & line. Brace properly.	put panels together, lift w/ crane, set panels, brace panels to plumb, clamp together
b. Diff. between wall/column assembly process?:	manufacturer of formwork (if rented) changes some of assembly.	Columns-corners interlocked, Walls-Sides tied and braced	Columns, snap ties, metal pre made form, sona tube.	slight difference in fabrication	N/A	lots of differences , snap ties vs taper ties	yes, each design is unique	Yes, different systems. Not on wall/colum n	Yes, mere bracing on walls. Different brace spacing. Thicker plywood. Depending on height thickness.	Yes, Differences present

Sl. no: of Respondents	11	12	13	14	18	19	20	21	22	23
Section 3. Assembly-										
c. Diff. between wall/column erection process?:		no	larger set with crane	no	N/A	Many differences, depends on form design	yes, each design is unique	set one side, brace	Diff. methods of leveling (level, laser, plumb bob)	Yes, Differences present
d. Connections Used-										
Mechanically driven	x					x			x	
Installed by hand	x	x	x	She-bolts		x	x	x	x	X
Others				lag screws(rotating drivers)				taper ties	John A Brackets, Hair pins	

Sl. no: of Respondents	1	2	3	4	5	6	7	8	9	10
Section 4. Stockpiling/storage-										
a. Before pouring Concrete:										

Sl. no: of Respondents	1	2	3	4	5	6	7	8	9	10
Section 4. Stockpiling/storage-										
i. Timeframe for which the formwork stays in place (days)	no typical timeframe	0-5	0-3	0-3	0-3	no typical timeframe	0-3	0-3	0-7	5-10
ii. External impacts during the timeframe:										
Wind	x			x			x	x	x	x
Personnel load	x	x	x	x		x	x	x		x
Equipment load	x					x				x
Others	Sun, rain, Vibration									
b. After pouring Concrete:										
i. Timeframe for which the formwork stays in place (days)	1	0-30, 0-2	1	1	1-2	depends on concrete, weather, and structure	1	1, depends on contract specs	1-14, avg 7	1-3
c. Seasonal variations:										
i. Is 4.b.i affected by season?	yes	no	no	yes	yes	yes	yes (freeze)	yes	yes	no

Sl. no: of Respondents	1	2	3	4	5	6	7	8	9	10
Section 4. Stockpiling/storage-										
ii. By how much?	Fall/ Winter by 24-72 hrs	none	none	1-2 days in winter		increases in cold/dry weather		depends on contract specs	doubles in winter	-

Sl. no: of Respondents	11	12	13	14	18	19	20	21	22	23
Section 4. Stockpiling/storage-										
a. Before pouring Concrete:										
i. Timeframe for which the formwork stays in place (days)	5-10	1-2	1-2	0,depends on thermal control	3 days	1 day min	no	2	3	-
ii. External impacts during the timeframe:										
Wind	x			x		x			x	
Personnel load	x	x	x	x		x	x		x	x
Equipment load	x			x		x	x		x	x

Sl. no: of Respondents	11	12	13	14	18	19	20	21	22	23
Section 4. Stockpiling/storage-										
Others				weight of other panels	Other trades knocking off alignment	Curing time		cranes can bump into it, weather	Platforms for working	
b. After pouring Concrete:										
i. Timeframe for which the formwork stays in place (days)	1-3	3	1	5	1	1 day	2-3, depends	1	1	1 day/next day
c. Seasonal variations:										
i. Is 4.b.i affected by season?	yes	yes	no	no	yes	yes	yes	no	yes	yes
ii. By how much?	increases by 3 days due to water	25% increase due to low temp. and water	-	-	1-2 days in really cold weather	1-2 days in summer/winter	increases in summer/wi nter	additives can be used to counter	increases by 1day in summer, and upto 3 days in Winter	Couple days in Winter

Sl. no: of Respondents	1	2	3	4	5	6	7	8	9	10
Section 5. Transportation & Removal-										

Sl. no: of Respondents	1	2	3	4	5	6	7	8	9	10
Section 5. Transportation & Removal-										
a. Method of removal:										
By hand	x	x	x	x	x	x	x	x	x	
Cranes/forklifts	x	x	x	x		x	x	x	x	x
others										
b. Movement of formwork:										
Within Site	Forklift/ Truck/trailer	Forklift, by hand	Forklift	Forklift	Forklift	Forklift/ crane, by hand	Forklift/ crane, by hand	Forklift/ crane, by hand	Forklift/ crane, by hand	Forklift
From Site-to site	Truck/trailer	Truck/trailer	Truck	Truck	Truck	Truck	Truck	Truck/trailer	Trucks/ Barges	Truck/trailer

Sl. no: of Respondents	11	12	13	14	18	19	20	21	22	23
Section 5. Transportation & Removal-										

a. Method of removal:										
By hand	x	x	x		x	x	x		x	x
Cranes/forklifts	x			x		x		x	x	x
others				Hydraulic ram	hammers, scarpers		depends on form construction	TRACKHOES		
b. Movement of formwork:										
Within Site	Forklift/crane	Forklift	Hands or forklift	Crane, Forklift	trucks/vans on lumber racks	Forklift	forklifts	Forklifts	By hand, Forklift	Cranes/Forklifts
From Site-to site	Truck/trailer	trucks	trucks	Forklift/trucks		Truck/trailer	truck	trucks, trailers	Trailer, Truck	Trucks, Trailers

Sl. no: of Respondents	1	2	3	4	5	6	7	8	9	10
Section 6. Degradation & Re-use:										
a. Observations:										
i. Commonly observed Degradations:										
Edges/Corners	x	x	x		x	x	x	x	-	x
Faces	x	x	x	x		x	x	x	-	
Structural Cracks	x					x		x	-	x

Sl. no: of Respondents	1	2	3	4	5	6	7	8	9	10
Section 6. Degradation & Re-use:										
Others	Warped, twisted, covered in concrete									Cupping & twisting
ii. Number of Uses										
Edges/Corners	varies greatly depending on personnel	1-2	2-3	-	3-5	depends on how formwork is treated	3-5	-	-	3
Faces		1-30	3-5	5-6	3-5		3-5	-	-	-
Structural Cracks		-	-	-	-		-	-	-	3
Others		Cutting or alteration of form								
b. No. of uses of each component:										
Component 1	2-3	1	Unlimited		3-5	Until thought to be no good	3-5	depends on how formwork looks, i.e condition	-	3-4
Component 2	2-10	100	Unlimited		5-20		5-20		-	3-4
Component 3	2-10 or more	varies	Unlimited						-	3-4
Component 4	many	1-10	Unlimited						-	
Connections	1-100		Unlimited						-	
c. Method of Assessment:										

Sl. no: of Respondents	1	2	3	4	5	6	7	8	9	10
Section 6. Degradation & Re-use:										
Visual Inspection	x	x	x	x		x	x	x	x	x
Others										
d. Deciding Factor against re-use:	depends on project, mostly finish	depends on the use	Surface & Structural Damage	Surface Finish		Required finish, and formwork condition	Cracks, cannot hold concrete	Holes, cracks,breaks	-	Ease of assembly
e. Manufacturer's Guidelines:										
i. Availability of guidelines:	not sure	no	no	no	no	no	yes	no	yes	no
ii. Guidelines taken into account (y/n):	no	no	no	yes	yes	no	yes	yes	yes, depending on specification	no

Sl. no: of Respondents	11	12	13	14	18	19	20	21	22	23
Section 6. Degradation & Re-use:										
a. Observations:										
i. Commonly observed Degradations:										
Edges/Corners	x	x	x	x	x	x	x		x	x
Faces	x	x		x		x	x	x	x	x
Structural Cracks		x	x		x				x	

Sl. no: of Respondents	11	12	13	14	18	19	20	21	22	23
Section 6. Degradation & Re-use:										
Others	Cupping & twisting		Warping		holes	delamination of plywood		shrinkage		Concrete Buildup
ii. Number of Uses					3-4		depends			
Edges/Corners	3	3	3-4	1		2-3		4	1	1
Faces	3	2	3-4	1		2-3		4	1	1
Structural Cracks	3		3-4						3	-
Others	depends on required finish	depends on the handling of forms	Wall finish forms only once					can depend on maintenance		Concrete Buildup- 1
b. No. of uses of each component:										
Component 1	3	multiple	3-4	10		10-20	2-3	20	5/10	1-10
Component 2	6	6	25	10		6-12	4	4	10	1-4
Component 3	3	6-7	1	10		1	many		50	1-4
Component 4	100	multiple	-	3-4		100	-	50	2	1
Connections	100	1		infinitely		1	1		1	1
c. Method of Assessment:										
Visual Inspection	x	x	x	x		x	x	x	x	x

Sl. no: of Respondents	11	12	13	14	18	19	20	21	22	23
Section 6. Degradation & Re-use:										
Others					craftsman's experience			quality of work required		
d. Deciding Factor against re-use:	Formwork condition and size	Condition of lumber	size	Cost of preparation		Warping	required finish	rot	Cracks, lefects, missing layers, delamination, visual	Broke, too cut up, warped, split, too short etc.
e. Manufacturer's Guidelines:										
i. Availability of guidelines:	yes	no	no	no	yes	no	yes	y	y	no
ii. Guidelines taken into account (y/n):	yes	no	no	no	not practical to use	no	no	depends on whether rented/owned	y	no

Sl. no: of Respondents	1	2	3	4	5	6	7	8	9	10
Section 7. Failure & Injuries:										
a. Typical causes of Failure:									-	
Connections/Ties	x	x		x		x	x			x
Bending	x					x				
Deflection	x							x		x
Shear								x		

Sl. no: of Respondents	1	2	3	4	5	6	7	8	9	10
Section 7. Failure & Injuries:										
Blowouts	x		x	x		x	x	x		x
Others		Inappropriately braced/formed								
b. Occurance of formwork failure on project (y/n)	small blowouts due to poor work	no	no	no	no	no	no	no	no	no
c. Occurance of minor injuries on project (y/n)	no	no	no	no	no	no	no	scratches, pinches	no	no
d. Number of minor injuries on project (y/n)	none	none	none	none	handful	none	none	handful	none	none

Sl. no: of Respondents	11	12	13	14	18	19	20	21	22	23
Section 7. Failure & Injuries:										
a. Typical causes of Failure:										
Connections/Ties	x	x	x					x	x	x
Bending								x	x	
Deflection	x						x		x	x

Sl. no: of Respondents	11	12	13	14	18	19	20	21	22	23
Section 7. Failure & Injuries:										
Shear									x	
Blowouts		x	x	x			x	x	x	x
Others	Mistakes in erection			Installation error	poor installation, insufficient span support	lack of maintenance, improper stripping	improper installation	higher rate of pour, fastening not perfect	Bracing failure	Wood break, material defect
b. Occurance of formwork failure on project (y/n)	no	no	no	y	no	sagging due to overload	no	no	N/A	Minor one, no significant impact
c. Occurance of minor injuries on project (y/n)	no	no	yes	y	no	yes	no	no	no	y
d. Number of minor injuries on project (y/n)	none	none	a few	60>	no	a few	none	none	N/A	5 approx

Sl. no: of Respondents	1	2	3	4	5	6	7	8	9	10	11	12
Section 8. Rated Impact on life cycle of formwork-												
Construction Loading	3	1	1	1	1	2	1	1	2	0	2	5
Climbing up	2	1	1	1	1	0	1	0	1	1	1	3
Warping	3	2	4	4	4	3	4	1	5	3	5	1

Cracks	2	3	4	4	4	2	4	3		-	4	2
Surface Damage	4	4	4	4	1	4	3	4	5	1	5	2
Storage conditions	2	3	3	3		4	3	2	1	3	5	3
Assembly	4	3	5	5	4	4	4	2	2	3	4	3
Design	4	2	0	1	4	3	5	1	5	1	5	4
Connections	4	3	4	4	4	3	4	1	3	1	4	4
Ties	4	3	3	3	5	4	3	1	3	1	4	4
Removal	4	2	5	5	1	5	5	3	5	1	4	2
Increase/decrease in temperature	2	0	3	3		2	3	0	1	3	3	1
Increase/decrease in humidity	2	0	3	3		2	3	0	1	3	3	1
Accidental impact	3	3	4	4		2	3	3	5	-	3	4
Other	-	-	-	-	-	-	-	-	-	-	Abuse-4	-

Sl. no: of Respondents	13	14	15*	16*	17*	18	19	20	21	22	23
Section 8. Rated Impact on life cycle of formwork-											
Construction Loading	0	5	3	3	2	3	4	2	4	5	5
Climbing up	0	1	0	0	2	-	1	2	1	3	1

Sl. no: of Respondents	13	14	15*	16*	17*	18	19	20	21	22	23
Section 8. Rated Impact on life cycle of formwork-											
Warping	5	1	4	3	1	5	5	3	2	5	4
Cracks	5	1	3	3	2	5	2	4	1	4	5
Surface Damage	5	3	1	2	1	5	5/1	4	4	3	4
Storage conditions	5	2	5	2	2	2	5	2	1	4	1
Assembly	1	1	3	2	1	4	5	4	3	5	2
Design	0	4	5	4	3	3	4	2	2	2	4
Connections	2	4	5	2	2.5	5	3	4	1	5	4
Ties	3	4	5	2	2	4	3	4	2	5	4
Removal	2	5	5	2	1.5	4	5	5	2	2	5
Increase/decrease in temperature	1	2	4	0	0	1	3	2	2	2	1
Increase/decrease in humidity	1	3	4	0	0	1	3	2	2	2-4	1
Accidental impact	2	2	1	0	0	-	2	4	3	3	4
Other	-	-	-	Rain-3	-	-	Oiling and stacking-5	-	Cleaning and oiling, especially if there are form liners-4	-	Concrete Build up- 4

**Respondents 15, 16 and 17 filled out only the impact tables.*

Section 8. Rated Impact on life cycle of formwork-	**Total Impact (sum)**
Construction Loading	56
Climbing up	24
Warping	77
Cracks	67
Surface Damage	73
Storage conditions	63
Assembly	74
Design	68
Connections	76.5
Ties	76
Removal	80.5
Increase/decrease in temperature	39
Increase/decrease in humidity	38
Accidental impact	55

APPENDIX – II: OSHA FATALITY AND CATASTROPHE SUMMARY REVIEW

	Report ID	Event Description	Trade	Severity	Hospitalized/Not	Activity	Cause
1	950632	Driver Sustains Fractures When Concrete Truck Topples	Truck driver	Medium	Yes	Pouring Conc	Trench near back of truck collapsed, causing truck to fall on driver, who was outside near back of truck
2	950614	Employee Cuts Hand With Circular Saw	C. Laborer	High	Yes	Forming	Accident
3	950643	Worker Lacerates Hand On Angle Grinder Used On Concrete	C. Laborer	Medium	Yes	Pouring Conc	Cause unspecified
4	111500	Four Employees Are Injured When Concrete Form Falls Over	C. Laborer	Low	Yes	Erection	Upright form collapsed on employee when brace was removed
5	950633	Employee Is Shocked In Contact With Overhead Power Line	Mason	High	Yes	Pouring Conc	Accidental Contact with Powerline
6	626000	Employee Dies From Heat Exhaustion	-	High	Fatality	Assembly	Employee collapsed from heat exhaustion and died
7	950611	Four Employees Are Injured When Roof Deck Collapses	Carpenter	Medium	Yes	Pouring Conc	Falsework design load underestimated, leading to collapse
8	950641	Employee Is Injured In Fall From High Wall	Carpenter	Low	No	Stripping	Slip from form
9	352410	One Employee Is Killed, Another Is Injured In Wall Collapse	C. Laborer	High	Fatality	Erection	Collapse of precast concrete wall
10	950641	Employee Is Injured In Fall	Carpenter	Medium	Yes	Pouring Conc	Employee slipped while tightening brace to form during pour
11	950624	Employee Is Struck And Injured By Hose	C. Laborer	Medium	Yes	Pouring Conc	Block in hose
12	111700	Worker Is Killed In Slip And Fall On Icy Surface	Truck driver	High	Fatality	Transportation	Ice on Concrete
13	524530	Employee Is Killed By Concrete Form Collapse	C. Laborer	High	Fatality	Pouring Conc	Culvert floor Form collapse
14	523900	Employee Is Killed When Wall Collapses	-	High	Fatality	Pouring Conc	Inadequate brace of forms for CIP Wall
15	214700	Employee Dies From Fall While Installing Scaffold	C. Laborer	High	Fatality	Forming	Fall of abt 6-7 ft
16	552651	Employee Is Killed When Crushed By Collapsing Wall	C. Laborer	High	Fatality	Other	Excavation to erect form

	Report ID	Event Description	Trade	Severity	Hospitalized/Not	Activity	Cause
17	950611	Worker Falls And Sustains Cuts To Hand And Arm	Finisher	Medium	Yes	Pouring Conc	
18	950631	Employee'S Fingertip Is Crushed When Chain Is Hoisted	Finisher	Medium	No	Pouring Conc	
19	950612	Employee Is Injured When Struck By Metal Concrete Form	C. Laborer	Medium	Yes	Other	Falling form
20	950641	Laborer Fractures Leg When Pinned By Concrete Vault Forms	C. Laborer	Medium	Yes	NS	Falling form
21	830300	Employee Is Killed In Excavation Cave-In	-	High	Fatality	Erection	Cave-In
22	134000	Employee Lacerates Leg While Cutting Wood With Portable Saw	-	Medium	Yes	Assembly	Saw recoil
23	523400	Employee Is Injured By Falling Concrete Forms	-	Medium	Yes	Forming	Pin holding forms in basket removed
24	1032500	Three Employees Injured In Collapse Of Bridge Being Built	Carpenter	Medium	Yes	Other	Deck formwork Collapse
25	950621	Employee Is Injured In Fall From Ladder	Foreman	Medium	Yes	Stripping	Struck by loose form
26	951510	Employee Is Injured Struck By Flying Object	Carpenter	Medium	Yes	Stripping	Struck by flying form
27	950633	Employee Injures Back In Fall From Scaffold	Mason	Medium	Yes	Other	Struck by form
28	950641	Employee Lacerates Thumb While Using Portable Electric Saw	Carpenter	Low	No	Assembly	Untrained?
29	950633	Employee Amputates Thumb While Using Portable Saw	C. Laborer	High	Yes	Forming	Cause Unspecified
30	134000	Worker Ripping Wood Amputates Thumb	-	High	Yes	Stripping	Safety Device inactive
31	1054113	Employee Injured In Fall From Bridge Scaffold Into River	C. Laborer	Medium	Yes	Stripping	Fall from Scaffold
32	215000	One Killed, One Injured When Concrete Forms Collapse	-	High	Fatality	Pouring Conc	Formwork Collapse
33	134000	Employee Sustains Fractures In Fall	-	Medium	Yes	Erection	Fall
34	953220	Seven Employees Injured When Concrete Form Collapses	Carpenter	Low	No	Pouring Conc	Shoring Failure
35	950615	Employee Amputates Three Fingers Using Circular Saw	C. Laborer	High	Yes	Forming	Saw blade Kick back
36	950613	Employee Injured In Same-Level Fall On	Carpenter	Medium	Yes	Forming	Lost Balance

	Report ID	Event Description	Trade	Severity	Hospitalized/Not	Activity	Cause
		Work Platform					
37	950611	Employee Injured In Backward Fall Off Column During Pour	Metal Worker	Medium	Yes	Pouring Conc	Column bar bent, letting hook slip out
38	950636	Employee Fractures Leg In Fall From Wood Formwork	Carpenter	Medium	Yes	Erection	Lost footing, no catenary lines attached
39	215000	Employee Killed In Fall When Plywood Panel Breaks Loose	-	High	Fatality	Forming	Stepped on unsupported deck form
40	352440	Employee Injures Shoulder In Fall Into Excavation	C. Laborer	Medium	Yes	Pouring Conc	Tripped over formwork
41	214700	Employee Killed In Fall From Work Platform	-	High	Fatality	Forming	Work platform slipped
42	950614	Employee Trips And Fractures Leg	Inspector	Medium	Yes	Other	Tripped over formwork
43	950632	Employee Injured When Knocked Down By Falling Coworker	Carpenter	Medium	Yes	Assembly	-
44	950621	Employee'S Fingers Lacerated When Power Saw Kicks Back	Finisher	Medium	Yes	Erection	Knot in wood
45	953220	Employee Killed In Apparent Fall Into Elevator Shaft	C. Laborer	High	Fatality	Other	-
46	729700	Employee Killed When Struck In Neck By Masonry Saw	C. Laborer	High	Fatality	Forming	Blade kickback
47	729700	Employee Killed When Struck In Neck By Masonry Saw	C. Laborer	High	Fatality	Forming	Blade kickback
48	950633	Employee Injured When Crushed By Collapsing Concrete Wall	Mason	Medium	Yes	Stripping	Wall collapse
49	216000	Employee Killed In Fall Through Floor Opening	-	High	Fatality	Other	Fall through form opening
50	454510	Employee Electrocuted When Bull Float Contacts Power Line	Finisher	High	Fatality	Other	Electrocution
51	950642	Employee Injured When Struck By Falling Piece Of Wall Form	Carpenter	Medium	Yes	Erection	Struck by components falling from crane
52	418800	Employee Killed In Fall Over Side Of High Rise	-	High	Fatality	Stripping	unstable position and fall, causing his lines to be snapped
53	950611	Employee Suffers Back Contusions In Fall From Work Platform	Carpenter	Medium	Yes	Forming	lost balance
54	453730	Employee Is Injured In Fall From Collapsed	Foreman	Medium	Yes	Erection	Damaged shores under deck form system

	Report ID	Event Description	Trade	Severity	Hospitalized/Not	Activity	Cause
		Deck					
55	552700	Nine Employees Are Injured When Concrete Forms Collapse	-	Medium	Yes	Pouring Conc	Deck formwork Collapse
56	352440	Employee Falls From Elevation, Sustains Minor Injuries	Carpenter	Medium	No	Forming	Tie-off point collapsed
57	453710	Employee Falls From Form Work, Fractures Wrist	-	Medium	Yes	Forming	Lost balance
58	950625	Employee Sustains Fractures When Struck By Falling Forms	C. Laborer	Medium	Yes	Transportation	Bands burst on stacks of slip forms
59	521700	Employee Is Struck And Killed By Falling Formwork	-	High	Yes	Erection	Choker cable detached from hook, toppling the form
60	953220	Employee Is Injured When Concrete Falsework Collapses	Carpenter	Medium	Yes	Stripping	System collapsed due to lack of balance
61	950614	Employee Suffers Burns To Feet From Contact With Wet Cement	Carpenter	Medium	Yes	Pouring Conc	Chemical burns, non-regulation footwear
62	950632	Employee Fractures Bones In Leg And Ankle In Fall From Beam	Carpenter	Medium	Yes	Forming	Lost balance while climbing down
63	1032500	Worker Is Killed When Crane Collision Topples Concrete Form	-	High	Fatality	NS	Crane collision, which knocked over precast form
64	419700	Employee Is Struck And Killed By Industrial Equipment	-	High	Fatality	NS	Struck by concrete mover when on the blind spot
65	953220	Two Employees Are Killed And Two Injured In Form Collapse	-	High	Fatality	Stripping	Form collapse
66	950631	Worker Falls And Fractures Leg	Carpenter	Medium	Yes	Erection	Sudden pull, causing worker to fall
67	950614	Employee Sustains Laceration And Fractures In Fall	-	Medium	Yes	Other	Fall
68	950641	Employee Is Injured When Column Form Collapses	C. Laborer	Medium	Yes	Erection	Worker cuts tie, causing form & rebar collapse
69	950643	Employee'S Hand Is Lacerated When Pinched By Casting	C. Laborer	Medium	Yes	Stripping	Misjudged force for rotation of fixture, inorder to place it upright
70	453720	Employee Is Struck By Falling Metal Panel And Paralyzed	-	High	Fatality	Stripping	Form fell from slipping co-worker's hands
71	950641	Employee Is Injured When Caught Between Lift And Ceiling	Carpenter	Medium	Yes	NS	Pushed wrong switch on forklift

	Report ID	Event Description	Trade	Severity	Hospitalized/Not	Activity	Cause
72	418600	Employee Is Struck And Killed By Concrete Formwork	-	High	Fatality	Stripping	-
73	419400	Employees Are Injured By Falling Concrete	-	Medium	Yes	Other	Stacked forms knocked over onto workers by crane
74	950624	Employee Fractures Clavicle In Fall From Truck	-	Medium	No	Transportation	Rope slipped, causing him to fall over
75	953220	No Injuries When Concrete Forms Displaced From Building	-	Low	No	NS	Flying forms displaced and fell 100 ft
76	1054112	Employee Killed When Struck By Falling Slab Of Concrete	-	High	Fatality	Forming	Concrete slab collapse
77	215600	Attic Collapses, Kills One Worker And Injures Three	-	High	Fatality	Pouring Conc	Deck formwork Collapse during pour
78	830300	Employee Is Killed In Fall From Slip Form Scaffold	-	High	Fatality	Other	Fall from scaffold, 110 ft
79	950622	Employee Is Injured In Fall From Concrete Formwork	Utility	Medium	Yes	Other	Support shores removed, causing formwork to collapse
80	418800	Construction Worker Is Killed In Fall Through Floor Opening	-	High	Fatality	Stripping	fall through floor opening, no fall protection
81	950612	Employee Amputates Finger While Assembling Concrete Parts	-	High	Yes	Assembly	Finger caught between form components
82	418100	One Employee Killed, One Injured In Hit-And-Run Accident	-	High	Fatality	Other	Hit & run
83	950611	Two Carpenters Are Injured When Falsework Collapses	Carpenter	Medium	Yes	Erection	Improperly designed falsework
84	950611	Two Ironworkers Are Injured When Falsework Collapses	Metal Worker	Medium	Yes	Erection	Improperly designed falsework(same incident as above)
85	950635	Worker Fractures Feet In Fall From Concrete Wall	-	Medium	Yes	Pouring Conc	Snap hook not fastened to approved anchor point
86	134000	Employee Falls And Fractures Skull	-	High	Yes	Forming	12ft fall
87	950644	Employee Is Injured In Fall From Wall From	C. Laborer	Medium	Yes	Erection	Employee was between tie off points
88	418800	Three Employees Are Killed, Fourth Injured, In Deck Collapse	-	High	Fatality	Pouring Conc	Deck forms collapse during pour
89	215600	Employee Dies After Being Struck By Concrete Forms	-	High	Fatality	Transportation	Falling forms

	Report ID	Event Description	Trade	Severity	Hospitalized/Not	Activity	Cause
90	352450	Employee'S Fingers Are Injured By Falling Object	C. Laborer	Medium	Yes	Assembly	Safety latch of sling holding form up failed, causing fall
91	112000	Employee Fractures Leg When Concrete Form Falls Over	Carpenter	Medium	Yes	Erection	Form tipping over
92	215000	Employee Is Killed In Collapse	C. Laborer	High	Fatality	Stripping	Vertical slab collapsed upon removal of form
93	950611	Employee Injured In Fall From Concrete Form During Pour	Foreman	Medium	Yes	Pouring Conc	No anchor points to tie off or appropriate scaffold
94	953220	Employee Is Injured In Fall From Cement Form	C. Laborer	Medium	Yes	NS	Form he was standing on shifted
95	950615	Employee Is Injured In Fall Through Floor Opening	Finisher	Medium	Yes	Other	fall from unprotected stairwell
96	950625	Employee Falls From Scaffold And Suffers Concussion	C. Laborer	Medium	Yes	Erection	Wind knocked over 4x8 panel held by worker
97	454712	Cave-In Kills Construction Worker	Carpenter	High	Fatality	Forming	Trench collapse, lack of shoring
98	950622	Employee Amputates Fingers On Circular Saw Blade	C. Laborer	High	Yes	Other	Saw jammed
99	953220	Employees Are Injured In Collapse While Pouring Concrete	C. Laborer	Medium	Yes	Pouring Conc	Deck form collapse
100	524200	One Employee Killed, Another Injured In Fall	-	High	Fatality	Stripping	Collapse of formwork and scaffolding
101	552700	Employee Is Killed In Fall Down Mechanical Shaft	-	High	Fatality	Erection	Fall through floor hole while inspecting forms
102	950621	Concrete Worker Sustains Fracture When Struck In Chest	Finisher	Medium	Yes	Pouring Conc	Surge chamber attached to concrete truck hit worker
103	950622	Employee Fractures Leg When Struck By Skid-Steer Loader	Carpenter	Medium	Yes	Assembly	Nearby loader backed up onto worker
104	950411	Employee Amputates Two Fingers In Precast Concrete Machine	C. Laborer	High	Yes	Forming	worker stuck his hand into gap into a machine used to form precast
105	523300	Employee Falls And Suffers Head And Back Injuries	-	Medium	Yes	Erection	18.6 ft fall
106	953220	Employee Is Injured In Fall And Dies Later	C. Laborer	High	Fatality	Forming	Cut rebar to which he was hooked to
107	420600	Employee Dies After Lacerating Leg With Saw	-	High	Fatality	Assembly	Saw stuck in leg, causing bleeding
108	627410	Employee Is Killed When Struck By Pickup Truck	-	High	Fatality	Transportation	Pinned to the bed of a truck by the pick up

	Report ID	Event Description	Trade	Severity	Hospitalized/Not	Activity	Cause
109	636900	Employee Is Killed In Fall When Board Comes Loose	Carpenter	High	Fatality	Forming	Displaced guardrail, causing employee to fall through opening
110	950621	Carpenter Is Injured In Fall From Ladder	Carpenter	High	Yes	Erection	lost balance on ladder
111	352430	Employee Is Injured In Formwork Collapse	C. Laborer	Medium	Yes	Pouring Conc	Collapse of formwork and scaffolding, cause unknown
112	950631	Employee Sustains Lacerations In Fall While Building Patio	Finisher	Medium	Yes	Pouring Conc	Slipped and fell onto uncapped concrete stakes
113	216000	Employee Dies After Being Struck By Concrete Form	C. Laborer	High	Fatality	Stripping	Form came off crane and struck worker
114	950613	Employee'S Leg Is Injured When Run Over By Tractor	-	Medium	Yes	Erection	Backed into by tractor
115	953220	Employee Dislocates Knee In Fall	Carpenter	Medium	Yes	Erection	Fall of 10-12 ft
116	257220	Employee Is Struck And Killed By Falling Crane Boom	-	High	Fatality	Erection	Struck by crane boom
117	521400	Formwork Collapses And Crushes Employee	-	High	Fatality	Erection	Improper temporary bracing, lack of guidelines
118	953220	Employee Is Injured After Falling From Work Platform	Carpenter	Medium	Yes	Stripping	Crane boom cable failure
119	552651	Employee Electrocuted While Working In Open Basement	C. Laborer	High	Fatality	Stripping	Faulty cable caused electrocution
120	950622	Employee Is Injured While Stripping Concrete Form	Finisher	Medium	Yes	Stripping	Scraped leg on uncapped state, causing infection
121	950411	Eleven Employees Are Injured In Deck Collapse	Finisher	Medium	Yes	Pouring Conc	Deck form collapse
122	418800	Employee Dies When Crushed By Storm Drain	-	High	Fatality	NS	Crushed between trench wall and catchbasin byaccident
123	728900	Employee Injured By Falling Form Wall	-	Low	No	Pouring Conc	Form broke at half-height, pinning his foot against wall
124	626700	Employee Is Struck And Killed By Falling Concrete Form	Carpenter	High	Fatality	Forming	form shifted and fell on worker
125	626000	Employee Killed When Struck By Falling Mass Of Concrete	C. Laborer	High	Fatality	Transportation	Form has become filled with concrete inadvertently
126	950642	Employee Injured In Fall When Raised Platform Collapses	C. Laborer	Medium	Yes	Erection	unsecured platform with no guardrails/toe boards
127	950644	Employee Is Injured In Trench Cave-In	C. Laborer	Medium	Yes	Erection	Cave-In while clearing water out of trench for

	Report ID	Event Description	Trade	Severity	Hospitalized/Not	Activity	Cause
							excavation
128	352440	Employee Is Injured When Struck On His Head By Concrete Form	C. Laborer	Medium	Yes	Stripping	Dropped form while slipping, hardhat fell off
129	1054113	Employee Is Injured When Struck By Falling Concrete	Carpenter	Medium	Yes	Erection	Crane dropped form by 1 ft
130	950641	Employee Fractures Both Legs When Concrete Form Strikes Him	C. Laborer	Medium	Yes	Stripping	Unrestrained form fell on him
131	418800	One Is Killed, Three Are Injured In Concrete Form Collapse	-	Medium	Yes	Stripping	Form fell on employee while stripping
132	854910	Employee Electrocuted While Extending Boom On Pump Truck	Finisher	High	Fatality	Pouring Conc	Boom touched overhead powerline, and worker closed circuit on ground
133	317900	One Employee Killed, One Hurt When Boom Strikes Power Line	-	High	Fatality	Pouring Conc	Boom touched overhead powerline, electrocuting the nearby personnel
134	950633	Employee Injures Leg When Struck By Precast Wall Panel	-	High	Yes	Stripping	Wall panel fell on worker's leg when formwork was stripped
135	625700	Two Employee Drown In A Lake	Carpenter	High	Fatality	Other	Unrelated to form work
136	453730	Three Employees Are Overcome By Carbon Monoxide	C. Laborer	Low	No	Pouring Conc	Exposure to Carbon Monoxide
137	453730	Three Employees Are Exposed To Carbon Monoxide	C. Laborer	Medium	Yes	Pouring Conc	Exposure to Carbon Monoxide
138	352410	Employee Injures Arm In Fall	C. Laborer	Medium	Yes	Stripping	Unhooked lanyard while stripping shores
139	950631	Employee Iamputates Thumb While Using Skil Saw	Mason	Medium	Yes	Other	Amputated thumb while using a skil saw
140	420600	Employee Dies After Falling From An Elevation	C. Laborer	High	Fatality	Stripping	Lost balance while stripping close to edge, falling <30ft
141	352440	Employee'S Fingers Amputated In Cement Mixer Nip Point	-	High	Yes	Pouring Conc	Worker's glove got caught in the nip point, pulling his hand in
142	418800	Employee Killed In Fall While Tying Rebars For Form	Carpenter	High	Fatality	Erection	Fell from scaffold
143	950632	Employee Is Injured In Fall From Work Platform	C. Laborer	High	Yes	Stripping	Fall from unprotected scaffole, no fall protection
144	830500	Employee Dies From Crushing Injuries	Truck driver	High	Fatality	Other	Crushed between lowboy trailer and screed machine

	Report ID	Event Description	Trade	Severity	Hospitalized/Not	Activity	Cause
145	316100	Employee Killed In Fall From Concrete Form Work	C. Laborer	High	Fatality	Forming	Slipped when climbing up formwork
146	522000	Employee Is Impaled After Fall From Formwork	Carpenter	Medium	Yes	Stripping	Lost balance after stepping on unsecured scaffold plank
147	950642	Employee Falls Into Trench And Is Injured	C. Laborer	Medium	Yes	Erection	Fall as formwork member came loose, no fall protection was used
148	523400	Employee Is Killed In Fall From Form Work Being Dismantled	C. Laborer	High	Fatality	Stripping	Fall at Height > 25ft
149	729700	Employee'S Toes Amputated By Concrete Form	C. Laborer	High	Yes	Transportation	3400 lb form fell off from a trailer and landed on employee
150	950411	Employee Injures Head When Struck By Form	C. Laborer	Medium	Yes	Stripping	Form broke off and fell on worker
151	355112	One Killed, One Burned When Truck Boom Strikes Power Line	-	High	Fatality	Pouring Conc	Electrocution
152	418800	Employee Killed When Struck By Falling Concrete Form	Carpenter	High	Fatality	Erection	Form collapsed when employee was attempting to secure bulkhead
153	950641	Employee Injured When Struck By Falling Form	-	Medium	Yes	Erection	Rigging tangled, causing form to fall
154	950621	Employee Injured In Entanglement And Fall	Finisher	Medium	Yes	Other	Foot caught between precast form and platform, causing fall
155	625700	Employee Electrocuted When Truck Boom Strikes Power Line	-	High	Fatality	Pouring Conc	Electrocution
156	552651	Employee Killed In Fall From Concrete Form	C. Laborer	High	Fatality	Stripping	Fall while removing crane hook
157	452110	Employee Killed And Another Injured When Form Fails	-	High	Fatality	Pouring Conc	Ties broke, causing form to fall/collapse on employees
158	950611	Employee Fractures Leg When Struck By Pole	C. Laborer	Medium	Yes	Forming	Employee struck by shore
159	215800	One Employee Killed And Nine Injured In Bridge Collapse	C. Laborer	High	Fatality	Pouring Conc	Lack of adequate bracing causing formwork t collapse
160	521700	Three Employees Injured When Concrete Pump Hits Power Line	-	Medium	Yes	Pouring Conc	Boom contacted overhead power lines
161	625700	Employee Is Killed When Concrete Formwork Collapses	-	High	Fatality	Erection	Formwork Collapse
162	729700	Employee Is Killed In Excavation Cave-In	Finisher	High	Fatality	Stripping	Excavation Collapse, no excavation protection

	Report ID	Event Description	Trade	Severity	Hospitalized/Not	Activity	Cause
							system used
163	215000	Employee Is Crushed And Killed By Falling Concrete Wall	Carpenter	High	Fatality	Assembly	Hoist pulling up wall failed, causing wall to collapse on worker
164	950611	Employee Is Killed In Fall From Golden Gate Bridge	Carpenter	High	Fatality	Assembly	Accident due to lack of requisite scaffolding
165	950642	Employee'S Thumb Is Lacerated By Circular Saw	C. Laborer	Medium	Yes	Assembly	Cause not determined
166	830600	Employee Killed In Fall After Suffering From Heart Failure	-	High	Fatality	Pouring Conc	Caused by heart attack/fall
167	950643	Employee Injured In Fall From Formwork	-	Medium	Yes	Assembly	Stiff-back to which worker attached his fall protection failed
168	950632	Employee Injured From 30 Ft Fall From Parking Garage	C. Laborer	High	Yes	Erection	Platform Collapse
169	552651	Employees Injured In Fall When Formwork Fails	C. Laborer	Medium	No	Pouring Conc	Formwork Failure
170	950632	Three Employees Burned By Propane Explosion	Various	Medium	Yes	Other	Propane tank leak caused explosion
171	751910	Employee Killed When Struck By Falling Load	C. Laborer	High	Fatality	Transportation	Load of concrete forms fell off the crane sling
172	626600	Employee Killed When Concrete Pump Truck Strikes Power Line	C. Laborer	High	Fatality	Pouring Conc	Electrocution
173	626700	Three Employees Injured When Struck By Concrete	C. Laborer	Medium	Yes	Pouring Conc	Concrete collapse
174	419700	Employee Electrocuted When Pump Truck Boom Contacts Power Li	-	High	Fatality	Pouring Conc	Electrocution
175	830500	Concrete Form Fell Killing Employee	Carpenter	High	Fatality	Stripping	Form was released and fell on the worker
176	418300	Employee Fell And Died After Bridge Form Fell	-	High	Fatality	Erection	Form the worker was standing on fell, causing a fall of >60ft
177	950621	Employee Injured When Hit By Come-Along	Finisher	Medium	Yes	Stripping	Form worked loose, hitting the employee in the face
178	355112	Employee Killed When He Is Struck In Chest With Wire Rope	C. Laborer	High	Fatality	Erection	Tensioning wire came loose, hitting the employee
179	950643	Employee Is Injured In Fall From Retaining Wall	C. Laborer	Medium	Yes	Stripping	Board came loose unexpectedly, causing worker to lose balance

	Report ID	Event Description	Trade	Severity	Hospitalized/Not	Activity	Cause
180	950651	Employee Pierced By Reinforcing Rods In Fall From Ladder	C. Laborer	Medium	Yes	Erection	Ladder slipped, causing worker to fall
181	950632	Employee Partially Amputated Thumb With Circular Saw	Painter	High	Yes	Assembly	Saw jumped off as it hit a knot in the wood, and hit worker's hand
182	521100	Employee Dies From Asphyxiation - Struck By Concrete Forms	C. Laborer	High	Fatality	Other	Form was inadequately braced
183	953210	Employee Injured When Safety Bolt Failed And Door Fell	-	Medium	Yes	Other	Safety bolt of vibrator connecting to a concrete steel form box
184	729700	Employee Died When Fell Onto An Impalement Hazard	-	High	Fatality	Pouring Conc	Worker fell as he was clearing the concrete chute
185	134000	Two Employees Injured When Concrete Form Fell Onto Scaffold	C. Laborer	Medium	Yes	Stripping	Form came loose and fell on scaffold, causing scaffold to collapse
186	552651	Employee Injured In Fall From Top Of Concrete Form	C. Laborer	Medium	Yes	Assembly	Worker slipped as he climbed up a 14ft formwork panel
187	215800	Employee Injured In Fall From Elevated Work Platform	-	Medium	Yes	Pouring Conc	Excavator pouring concrete accidentally hit employee, causing fall
188	352440	Employee Injured In Fall When Concrete Floor Deck Collapses	Supervisor	Low	No	Other	Bar joints rolled,causing deck concrete to collapse
189	216000	Employee Killed In Fall From Hanging Scaffold	-	High	Fatality	Stripping	Tractor trailer hit ladder as employee was descending, causing fall
190	950615	Employee Injured In Fall From Formwork Wall	Carpenter	Medium	Yes	Pouring Conc	Lack of adequate work platform/scaffold
191	625400	Three Employees Drown When Concrete Form Collapses Into Lake	-	High	Fatality	Pouring Conc	Form blowout caused employees (tied off to top of form) to fall into lake
192	1055350	Employee'S Back Fractured When Struck By Falling Boom	-	High	Yes	Pouring Conc	Part of pumping apparatus came loose
193	950611	Employee'S Ankle Fractured When Excavation Wall Collapses	C. Laborer	Medium	Yes	Assembly	Excavation Collapse
194	950622	Employee'S Groin Impaled In Fall On Metal Stake	C. Laborer	High	Yes	Erection	Worker slipped and fell into 24'' deep trench
195	950632	Employee'S Leg Fractured In Fall From Form Wall	Carpenter	Medium	Yes	Other	Positioning belt on the worker's lanyard broke
196	950622	Employee Injured In Fall From Ladder	C. Laborer	Medium	Yes	Pouring Conc	Forms separated from wall, causing worker to lose balance

	Report ID	Event Description	Trade	Severity	Hospitalized/Not	Activity	Cause
197	317000	Eight Employees Injured When Forms For Access Ramp Collapsed	-	Medium	Yes	Pouring Conc	Improperly installed PERI form system
198	950613	Employee'S Finger Amputated When Ring Is Caught By Nail	-	High	Yes	Erection	Ring caught on nail, causing amputation
199	215000	Employee Killed When Building Collapses	-	High	Fatality	Pouring Conc	Building collapsed all the way to basement, asphyxiating employee
200	950635	Employee Injures Head In Fall From Concrete Form	Carpenter	High	Yes	Erection	Fall from a height of 12 ft
201	418800	Employee Killed In Fall While Removing Concrete Forms	Carpenter	High	Fatality	Forming	Lost balance while climbing down and fell (65 feet)
202	854910	Employee Injured In Fall While Stripping Concrete Forms	Carpenter	Medium	Yes	Stripping	Stripping concrete forms when he fell (31 feet)
203	950635	Employee Injured In Fall Through Form Work Decking	C. Laborer	High	Yes	Erection	Fall 16 feet
204	352420	Employee's Back Injured In Fall From Concrete Form	C. Laborer	Medium	Yes	Pouring Conc	Knocked off by the formwork wall and fell
205	854910	Employee Injured When Struck By Concrete Forms	Finisher	Medium	Yes	Stripping	Struck by falling slab
206	950645	Employee Hit On Head By Mandrel	C. Laborer	Low	No	Pouring Conc	Striking by the mandrel fell
207	419700	Employee Killed When Crushed Between A Form And Column	C. Trades	High	Fatality	Forming	Striking by the flipped up table
208	454510	Employees Injured When Struck By Rebar Cage	C. Trades	Low	No	Other	Toppled over by the cage
209	257220	Employee Killed In Excavation Cave-In	Utility	High	Fatality	Erection	Collapse of structure
210	418800	Employee Killed In Fall With Concrete Column Form	Carpenter	High	Fatality	Forming	Fall 130 feet
211	950611	Employee Injured When Steel Column Fell Over	C. trades	Medium	Yes	Erection	The column fell over on him
212	111400	Two Employees Injured When Block Wall Collapses	Various	Medium	Yes	Pouring Conc	Trapped by the collapsed wall, wall was inadequately braced
213	729700	Employee Injured In Fall From Concrete Form	C. Laborer	Medium	Yes	Forming	Falling 7 feet
214	950611	Employee Killed When Struck By Concrete	Carpenter	High	Fatality	Pouring	Collapse of structure

	Report ID	Event Description	Trade	Severity	Hospitalized/Not	Activity	Cause
		Column				Conc	
215	1032300	Employee Crushed By Concrete Form	Finisher	High	Fatality	Forming	Crushed by the panel
216	111400	Employee Killed In Fall From Scaffold Platform	-	High	Fatality	Pouring Conc	Falling 16 feet
217	830600	A Concrete Form Falls On Employees	-	High	Fatality	NS	Cause of form fall not specified
218	627100	Employee Killed In Fall When Bridge Form Collapses	-	High	Fatality	Other	Falling
219	1055320	Employee Dies After Suffering Heart Attack	-	High	Fatality	Other	Falling
220	830600	One Employee Injured In Fall When Roof Decking Fails	-	Medium	Yes	Pouring Conc	Collapse of structure
221	935000	Employee Killed When Concrete Structure Collapses	C. Laborer	High	Fatality	Other	Collapse of structure
222	418800	Three Employees Injured In Fall When Concrete Form Collapses	-	Medium	Yes	Pouring Conc	Collapse of structure
223	729300	Five Employees Injured When Concrete Form Collapses	Various	Medium	Yes	Pouring Conc	Collapse of shoring, cause unspecified
224	854910	Employee Injured When Weld On Concrete Form Fails	Supervisor	Medium	Yes	Transportation	Collapse of structure
225	950643	Employee Injured When Cut With Saw	Carpenter	Medium	Yes	Forming	Struck by the saw table
226	950613	Employee Injured In Fall From Concrete Form	-	Medium	Yes	Erection	Falling 4 feet
227	751910	Employee Killed When Crushed By Concrete Form	-	High	Fatality	Stripping	Crushed by falling object
228	950622	Employee Injured In Fall From Retaining Wall	Carpenter	High	Yes	Erection	Falling
229	626300	Employee Killed In Fall When Work Platform Fails	-	HIgh	Fatality	Forming	Falling from eleventh floor
230	112000	Employee Injured In Fall When Scaffold Bracket Fails	-	Medium	Yes	Pouring Conc	Collapse of structure
231	418200	Employee Killed In Fall From Building Under Construction	C. Laborer	High	Fatality	Other	Falling 100 feet
232	854910	Employee Injured In Fall From Concrete Wall	Carpenter	Medium	Yes	Stripping	Falling 12 feet
233	729700	Six Employees Were Injured When Scaffolding Collapses	-	Medium	Yes	Pouring Conc	Falling 16 feet

	Report ID	Event Description	Trade	Severity	Hospitalized/Not	Activity	Cause
234	418200	Employee Injured By Form Work When Crane Boom Fails	-	Medium	Yes	Forming	Collapse of structure
235	627700	One Employee Killed, One Injured By Falling Concrete Form	-	High	Fatality	Pouring Conc	Falling
236	522000	Employee Injured When Knocked Off Form Work By Swinging Load	-	Low	Yes	Erection	Falling 7.5 feet
237	830500	Employee Killed When Struck By Boom On Concrete Pump Truck	-	High	Fatality	Pouring Conc	Collapse of structure
238	352410	Employee Injured In Fall When Guardrails Collapse	Finisher	Medium	Yes	Stripping	Falling
239	355118	Two Employees Injured When Concrete Forms Collapse	Carpenter	Medium	Yes	Erection	Collapse of structure
240	950622	Employee Injured In Fall From Scaffold	Utility	Medium	Yes	NS	Falling
241	257210	Employee Killed When Struck By Collapsing Wall	Carpenter	High	Fatality	Erection	Block wall collapsed on employee
242	950613	Employee Injured In Fall Due To Concrete Form Collapse	Finisher	Medium	Yes	Pouring Conc	Deck form Collapse
243	950631	Employee Killed In 27 Ft Fall From Concrete Forms	C. Laborer	High	Fatality	Stripping	Fall when moving laterally, for which his lanyard was unhooked
244	352450	Two Employees Injured In Fall When Aerial Lift Overturns	Metal Worker	Medium	Yes	Stripping	Unexpectedly loosened form hit the aerial lift basket
245	1054111	Employee Injured In Fall From Shoring Towers	Carpenter	Medium	Yes	Stripping	Worker was standing on structurally unsound supports
246	950614	Employee Injured In Fall From Wall	Metal Worker	Medium	Yes	Erection	Cause unspecified, woeker was using full fall protection
247	625400	Employee Killed In Fall From Elevation	-	High	Fatality	Stripping	Lost balance while pullling off a nail from the form
248	213400	Employee Killed When Concrete Wall Collapses	-	High	Fatality	Other	Wall collapse as worker was erecting a precast panel
249	524200	Employee Killed When Crushed By Formwork	-	High	Fatality	Forming	Form fell on employee, cutting him inhalf
250	953220	Employee Injured In Fall When Formwork Collapses	Finisher	Medium	Yes	Pouring Conc	Form blew out during pour
251	953220	Employee Injured When Formwork Scaffold	Inspector	Medium	Yes	Pouring	Formwork scaffold collapse

	Report ID	Event Description	Trade	Severity	Hospitalized/Not	Activity	Cause
		Collapses				Conc	
252	854910	Employee Killed In Collapse Of Concrete Wall And Forms	C. Laborer	High	Fatality	Pouring Conc	Worker got pinnd by forms & Concrete as he was trying to brace a blowout
253	950623	Employee Injured When Struck By Falling Form Work	Supervisor	Medium	Yes	Stripping	Working under unsupported formwork
254	551800	Employee Killed When Struck By Falling Concrete Form	Finisher	High	Fatality	Forming	Another form fell off a pallet and hit worker on the head
255	950641	Employee'S Head Lacerated In Fall From Concrete Wall	Carpenter	Medium	No	Erection	Support worker was holding on to broke, causing him to fall
256	950641	Two Employees Injured When Rebar Cage Overturns	Carpenter	High	Yes	Erection	Inadequately braced rebar cage and form overturned when released by crane
257	355118	Employee Injured In Fall From Scaffold On Bridge	C. Trades	Medium	No	Stripping	Form on worker's end came loose, causing employee to fall through/over wire guardrail
258	454510	Employee'S Back Injured In Fall Across Floor Opening	Carpenter	Low	No	Forming	Stumbled and fell into opening
259	728900	Employee Dies After Suffering Heart Attack	-	High	Fatality	Stripping	Sudden heart attack
260	950615	Employee Injured In Fall From Wall	Supervisor	Medium	Yes	Erection	Working without any fall protection system in place
261	454510	Employee Injured When Struck By Falling Concrete Form	C. Trades	Medium	No	Erection	Panel slipped off the bottom panel and fell on worker
262	950613	Employee Injured In Fall When Plywood Filler Gives Way	C. Trades	Medium	Yes	Erection	Worker stepped on unsecured plywood bridging 2 sections of deck forms
263	950615	Carpenter Fractures Ankle In Fall From Ladder	-	Medium	Yes	Erection	Form shifted, pushing against ladder and causing worker to lose balance
264	418800	Employee Killed When Struck By Falling Form	-	High	Fatality	Stripping	Unsecured form fell on employee after he removed locking nut from tie bar
265	950632	Mason Fractures Tibia When Concrete Form Brace Gives Way	Mason	Medium	Yes	Pouring Conc	Stepped on brace not designed to support that load, and fell 3.5 ft
266	418800	Employee Killed When Struck By Falling Block Wall Section	-	High	Fatality	Erection	formwork fell on employee as he worked on forms due to crane 2 sections away
267	950623	Employee'S Ankles Fractured In Fall From Scaffold Platform	-	Medium	Yes	Erection	Worker fell off an unguarded platform as he was erecting falsework

	Report ID	Event Description	Trade	Severity	Hospitalized/Not	Activity	Cause
268	627100	Employee Killed When Caught Between Concrete Form And Wall	-	High	Fatality	Pouring Conc	Manhole form tipped over, asphyxiating worker under 4 yards of concrete
269	1032500	Employee Dies After He Falls From Concrete Form	-	High	Fatality	Forming	Worker fell 30ft while climbing down form as he could not tie off during descent.
270	950632	Employee Fractures Leg In Fall While Removing Concrete Forms	Carpenter	Medium	Yes	Stripping	Worker slipped and fell 4 feet onto a pile of forms
271	355114	Employee Breaks Hip In Fall	-	Medium	Yes	Stripping	Lanyard fastening slipped/broke/came loose, causing employee to fall 25 ft
272	1055360	Two Employees Injured By Falling Concrete Wall	-	High	Yes	Forming	Form fell, crushing workers
273	551800	Employee Dies From Blow To Head In 12 Ft Fall	Supervisor	High	Fatality	Stripping	Lost balance and fell from unguarded platform
274	418200	Employee Killed In Unprotected 30 Ft Fall	-	High	Fatality	Erection	Worker climbed over gaurdrailand worked on a 4x4 w/o fall protection
275	418800	Employee Dies When Trapped By Overturned Concrete Form	-	High	Fatality	Forming	Wind overturned form that the worker was tied off to
276	1054115	Employee Fractures Heels In Fall To Compacted Soil	Finisher	Medium	Yes	Stripping	Fall from ht of 14.5 ft as worker lost balance. He hadn't used his harness
277	521700	Employee Killed By Collapsing Concrete Form	-	High	Fatality	Stripping	Worker removed bolts before form carrier was in place, tunnel lining formwork
278	452110	Employee Killed In Fall From Concrete Forms	Supervisor	High	Fatality	Pouring Conc	Fall from 10-12 ft height, caused by slip or stepping from 12 ft to 10 ft level
279	950631	Employee Injured In Fall From Column When Lanyard Hook Slips	Carpenter	Medium	Yes	Erection	Lanyard hook slipped, causing employee to fall
280	352440	Employee Injured By Falling Brick Wall	Mason	Medium	Yes	Pouring Conc	Brick wall, also being used and formwork, failed and hit worker below 4 floors
281	453710	Employee Injured In Fall Onto Steel Reinforcing Bar	Carpenter	Medium	Yes	Erection	Plywood failed, causing the John clamp t which he was tied off to fail
282	950652	Employee Falls 14 Ft From Elevated Whaler	Carpenter	Medium	No	Stripping	Welding defect on steel whaler caused whaler to detach, causing the fall
283	352450	Employee Dies Of Cardiac Arrhythmia	Inspector	High	Fatality	Erection	Cardiac Arrhythmia
284	950623	Employee'S Thumb Amputated By Skil Saw	Carpenter	High	Yes	Assembly	Saw blade kicked back, and worker was not using a sawhorse

	Report ID	Event Description	Trade	Severity	Hospitalized/Not	Activity	Cause
285	523400	Employees Injured During Fall With Formwork	-	Medium	Yes	Pouring Conc	Deck form collapse due to underdesign and overload
286	950631	Employee Injured As Falsework Collapses	-	Medium	Yes	Pouring Conc	No cause for falsework collapse reported
287	950631	Employee Killed In Falsework Collapse	-	High	Fatality	NS	Falsework above employee collapsed duringpour
288	134000	Eight Employees Injured As Concrete Form Collapses	-	Medium	Yes	Pouring Conc	Falsework system faied during waffle slab pour
289	950652	Employee Falls Onto Mine Jaw Crusher From Wall	-	Medium	Yes	Pouring Conc	Lost balance and fell from top of formwork for a distance of 35 ft approx
290	352440	Two Employees Injured In Fall From Concrete Form	C. Laborer	Medium	Yes	Pouring Conc	Unguarded boom struck worker #1, who knocked over worker #2 and fell 6 ft
291	953220	Employee Crushed And Killed During Concrete Pour	Supervisor	High	Fatality	Pouring Conc	Boom section fell apart due to rust, crushing employee
292	1054112	Employee Fractures Back In 12 Ft Fall	Carpenter	Medium	Yes	Erection	Worker grabbed a section of rebar that came loose, causing him to fall
293	112300	Employee Killed During Excavation Cave-In	-	High	Fatality	Erection	Excavation (25 ft high) collapse
294	636900	Employee Injured When Struck By Falling Concrete Bucket	-	Medium	Yes	Pouring Conc	Bucket knocked employeeoff form and snapped his lanyard, causing him to fall
295	830500	Employee Sprains Back Muscles In Fall	-	Medium	Yes	Stripping	Fall from 3 ft, cause unknown
296	931300	Employee Killed When Struck By Falling Load	-	High	Fatality	Pouring Conc	crane hoist failed, dropping bucket ehich fell on the worker's head
297	626300	Employee Killed In Fall In Elevator Shaft	Supervisor	High	Fatality	Stripping	Formwork collapse
298	950641	Employee Struck By Descending Manlift	Carpenter	Medium	No	Erection	Worker looked into manlift shaft for locating center of a beam and got struck
299	950613	Employee Injured In Fall While Taking Down Concrete Forms	-	Medium	Yes	Stripping	Form member released before worker could hook his fall protection after descent
300	453710	Employee Hospitalized After Falling 60 Ft In Dam	Carpenter	Medium	Yes	Erection	Formmember moved during pour in another section, causing collapse
301	419700	Employee Killed When Struck By Front End Loader	-	High	Fatality	Stripping	Worker exited the loader but left the loader running without setting brake
302	551800	Employee Sustains Multiple Injuries In Fall From Wall	Carpenter	Medium	Yes	Stripping	Form was lifted without tagline after stripping, kocking worker off balance
303	522500	Employee Killed In Fall From Concrete	-	High	Fatality	Stripping	Employee removed scaffold bracket that he was

	Report ID	Event Description	Trade	Severity	Hospitalized/Not	Activity	Cause
		Formwork					tied off to
304	418800	Employee Killed In Fall From Open-Sided Building	-	High	Fatality	Stripping	Backed out of the unguarded side of building, no mention of fall protection
305	950411	Employees Killed When Struck On Head By Concrete Form	Various	High	Fatality	Transportation	Lifting plate broke, casing form to crush both employees
306	751910	Employee Struck And Killed By Falling Concrete Bucket	C. Laborer	High	Fatality	Pouring Conc	Bucket fell and hit worker, causing him to be crushed against platform
307	950641	No Injuries When Bridge Support Collapses	-	Near Miss	No	NS	Wood Falsework and steel support beams fr the bridge collapsed, cause not specified
308	625400	Employee Dies Of Heat Stress	-	High	Fatality	Other	Died due to heatstroke/hyperthermia
309	950631	Employee Sustains Compound Fracture Of Right Arm In Fall	-	Medium	Yes	Erection	Lanyard was dislodged, causng fall.
310	111400	Employees Bruised In Fall When Support Forms Fail	-	Low	No	Other	Deck form collapse due to overload
311	950641	Employee Injured In Fall From Cross-Stringer	Carpenter	Medium	Yes	Erection	Piece of form fell from crane, striking unsecured employee
312	950645	Employee Injured When Struck By Falling Wooden Form	Supervisor	Medium	Yes	Erection	Worker was standing on form, causing it to fall on him
313	625700	Employee Dies When Struck In Head By Falling Conveyor	-	High	Fatality	Erection	Conveyor was jarred, causing support to collapse and conveyor to fall
314	551800	Employee Injured In 6 Ft Fall	C. Laborer	Medium	Yes	Stripping	Lost balance and fell 6.5 ft.
315	950633	Employee Injured When Struck By Crane Bucket	Finisher	Medium	Yes	Other	Crane moved by itself, causing bucket to strike worker
316	352420	Employee Bruised In Fall From Scaffold	Carpenter	Medium	Yes	NS	Crane turned over due to rain, and caused worker to fall from platform
317	355114	Employee Killed In Fall From Bridge Abutment	Carpenter	High	Fatality	Stripping	Removed whaler that he was tied off to
318	953210	Employee Suffers Chemical Burn On Foot From Wet Cement.	Carpenter	Medium	No	Pouring Conc	Wet concrete got into his shoes, causing a chemical burn
319	454510	Five Employees Injured In Fall From Elevated Highway Span	Various	Medium	Yes	Pouring Conc	Friction collar failure
320	951510	Employee Injured When Struck By Concrete Wall Form	Carpenter	High	Yes	Erection	Wall form tipped over and struck Worker

	Report ID	Event Description	Trade	Severity	Hospitalized/Not	Activity	Cause
321	215000	Employee Killed In Fall	-	High	Fatality	Pouring Conc	Fall cause not specified
322	931300	Employee Dies In Fall From Platform	-	High	Fatality	Stripping	Shoring removed by other company personnel, causing formwork to fail
323	418200	Employee Injured In Fall From Structure	Carpenter	Medium	Yes	Erection	Worker fell off while helping to shorten bracing
324	215300	Employee Killed And Two Injured By Falling Concrete Form	-	High	Fatality	Erection	Crane operator's foot slipped on the brake pedal, causing form to fall
325	1055340	Two Employees Injured When Concrete Gang Form Falls	-	Medium	Yes	Erection	Not following manufacturer's recommendations while lifting gangform
326	950644	Employee Contracts Tetanus After Stepping On Drill Bit	-	High	Yes	NS	Worker stepped on drill bit protruding from poured concrete
327	950641	Employee Killed When Struck By Concrete Form Panel	C. Trades	High	Fatality	NS	1000lb unsecured form fell on worker
328	552651	Employee Falls 272 Ft To His Death	-	High	Fatality	Stripping	Worker was signaling to crane when he stepped into a gap
329	551800	Employee Impaled After Fall From Reinforcing Steel	Carpenter	Medium	Yes	Assembly	Worker stepped on an inadvertently cut rod and fell
330	454510	Employee Falls Into Trench And Is Impaled By Rebar	Carpenter	Medium	Yes	Erection	Fell into unguarded excavation
331	950411	Employee Injured In Fall From Deck	Finisher	Medium	Yes	Pouring Conc	Deck form collapse, reason unspecified
332	214700	Employee Injures Eye In Floor Collapse	C. Laborer	Medium	Yes	Pouring Conc	Deck formwork collapsed and worker got concrete inhis eye
333	751910	Employee Killed In Fall From Collapsing Concrete Slab	C. Trades	High	Fatality	Erection	Precast cement slab was being erected, which fell due to hoisting mechanism separating
334	950631	Employee Injured In Fall Onto Construction Materials	-	Medium	Yes	Forming	Lost footing and fell onto rebar
335	453710	Two Employees Injured When Struck By Crane Boom	C. Trades	Medium	Yes	Pouring Conc	Crane tipped over, striking formwork and workers
336	111400	Employee Killed When Struck By Steel Plate	C. Trades	High	Fatality	Erection	Unsecured steel plate used as formwork fell on worker
337	950626	Employee Injured In Fall From Symons Forms	Supervisor	Medium	Yes	Erection	Fell while climbing to work position

	Report ID	Event Description	Trade	Severity	Hospitalized/Not	Activity	Cause
338	551800	Employee Suffocates Under Dirt After Cave-In	-	High	Fatality	Erection	Unsupported excavation (type C-loose sandy soil) caved in on worker
339	1055340	Employee Falls From Cement Form, Dies Two Months Later	Carpenter	High	Fatality	Stripping	Not sure about cause
340	636900	Employee Killed In Fall From Concrete Form	-	High	Fatality	Pouring Conc	Lost balance after unhooking fall protection
341	454510	Employee Killed In Fall From Concrete Scaffold Bracket	C. Laborer	High	Fatality	Stripping	Fell from a ht of 8ft, cause of fall unknown
342	418100	Employee Killed In Fall Down Elevator Shaft	-	High	Fatality	Stripping	Slipped and fell into elevator shaft
343	552700	Employee Killed In Bridge Formwork Collapse	Supervisor	High	Fatality	Other	Truss supporting concrete arch collapsed
344	453710	Employee'S Hand Lacerated By Nail In Falling Concrete Form	Carpenter	Low	No	Stripping	Form fell off, hitting employees hand
345	953210	Employee Injured When Struck By Falling Beam	C. Laborer	Medium	Yes	Stripping	Formwork system collapse, cause unknown
346	1055320	Employee'S Toe Broken In Fall From Girder	Supervisor	Medium	No	Erection	Work platform gave way
347	951510	Employee Injured In Fall With Tubular Steel Concrete Shoring	Carpenter	Medium	Yes	Stripping	Shoring system tilted and fell with employee on it
348	355111	Employee Killed In Fall Down Elevator Shaft	C. Trades	High	Fatality	Forming	Slip or trip, causing fall >200 ft
349	453710	Employee Injures Knee In Trench Cave-In	C. Laborer	Medium	No	Erection	Unsupported excavation collapse
350	521700	Employee Killed By Falling Equipment	-	High	Fatality	Other	Pouring set-up collapsed on top of worker
351	352440	Employee Fractures Neck In Fall From Bridge	Carpenter	High	Yes	Erection	Form fell, pushing employee off the edge of bridge
352	418100	Concrete Form Work Collapsed	-	Near Miss	No	Pouring Conc	Cause unspecified
353	953220	Fall From Concrete Form	Carpenter	Medium	Yes	Forming	Work platform collapse
354	953220	Employee'S Abdomen Punctured In Fall Onto Rebar	Carpenter	Medium	Yes	Erection	Lanyard disengaged, causing fall
355	626300	One Employee Dies, Five Others Injured In Bridge Failure	-	High	Fatality	NS	Formwork system filure, cause unspecified
356	418800	Employee Killed In Nineteen Story Fall After Losing Balance	-	High	Fatality	Stripping	Lost balance
357	933300	Employee Killed In Fall With Column	-	High	Fatality	Erection	Column form collapsed due to another striking it

	Report ID	Event Description	Trade	Severity	Hospitalized/Not	Activity	Cause
358	453710	Employee Injured In Fall While Removing Formwork	Carpenter	Medium	Yes	Stripping	Hook on harness failed
359	454510	Iron Worker Injured In Fall From Concrete Form	Metal Worker	Medium	Yes	NS	Slipped while decsending rebar
360	931700	Employee Injured In Fall From Concrete Form	C. Trades	Medium	Yes	Other	rebar broke as employee leaned into it
361	112600	Employees Injured In Floor Collapse	-	Medium	Yes	Pouring Conc	Deck formwork collapse, cause unspecified
362	352420	Employee Injured In 13 Ft Fall From Scaffold	Supervisor	Medium	Yes	Stripping	Fell off unguarded scaffold
363	729300	Employee Dies In Scaffold Collapse	-	High	Fatality	Pouring Conc	Scaffold collapse due to lateral pressure caused by concrete from failed formwork
364	418800	Employee Dies Of Heat Stroke	-	High	Fatality	Erection	Death due to heatstroke/cancer
365	626300	Six Employees Injured In Fall From Bridge Under Construction	-	Medium	Yes	Pouring Conc	Bridge formwork collapse, reason unspecified
366	355114	Employees Are Burned While Pouring Concrete Forms	Finisher	Medium	No	Pouring Conc	Chemical burns caused by lack of protective clothing
367	627400	Two Killed, Six Injured When Concrete Bridge Deck Collapses	-	High	Fatality	Pouring Conc	Lack of sufficient amount of shoring, causing pan forms to collapse
368	352430	Employees Injured When Concrete Deck Collapses During Pour	Various	Low	No	Pouring Conc	Deck formwork failure, cause unspecified
369	626300	Construction Worker Killed In Fall; Not Tied Off	-	High	Fatality	Erection	Worker was at a height of 41 ft w/o fall protection
370	352440	Construction Worker Injured In Fall From Concrete Formwork	Carpenter	High	Yes	Erection	Worker was at a height of 25 ft w/o fall protection
371	454714	Construction Worker Injured In Fall From 10 Foot High Wall	Carpenter	High	Yes	Stripping	Worker was at the 10 ft ht w/o fall protection
372	551800	Employee Killed In Fall From Concrete Bridge Construction	C. Trades	High	Fatality	Assembly	Tripped and fell from unguarded wooden platform on Bridge
373	931700	Employee Killed In Fall From Temporary Work Platform	Carpenter	High	Fatality	Erection	Plywood on scaffolding failed at a preexisting borehole, causing scaffold failure
374	418100	Employee Killed In Fall From High-Rise Building	C. Laborer	High	Fatality	Other	Worker fell backwards whil putting up wire guardails
375	214200	Two Employees Killed, Two Hospitalized, By Collapsing Boom	-	High	Fatality	Transportation	Boom of crane broke, causing plywood to fall on workers

	Report ID	Event Description	Trade	Severity	Hospitalized/Not	Activity	Cause
376	551800	Employee Falls From Elevation, Dies	Engineer	High	Fatality	NS	Worker was climbing up form w/o fall protection, lost balance and fell 15 ft
377	418100	Employee Injured When Hit By Shoring	-	Low	No	Erection	Wind caused shoring with insufficient bracing to collapse
378	352440	4 Construction Workers Hurt When Metal Concrete Forms Fell	Finisher	Medium	Yes	Pouring Conc	Formwork collapse due to inadequate shoring/design
379	931700	Employee Struck By Falling Concrete Formwork Later Dies	C. Laborer	High	Fatality	Other	Formwork fell on employee, cause unspecified
380	215800	Two Employees Injured In Natural Gas Explosion	-	Medium	Yes	Erection	Gas leak caused by excavation activities caused explosion, ignition cause unknown
381	454713	Construction Employee Killed When Struck By Concrete Truck	C. Trades	High	Fatality	Pouring Conc	Second Truck ran into the first truck, knocking it into forms and crushing worker
382	931400	Employee Injured In Fall Onto Unprotected Rebar	-	High	Yes	Erection	Fall cause unspecified
383	552700	Two Employees Injured When Bridge Forming Collapses	-	Low	No	Pouring Conc	Formwork collapse, possibly due to revised design with lesser material
384	728900	Electric Shock - Cause Unknown	-	High	Fatality	Pouring Conc	Possible grounding fault
385	454714	Employee Fractures Leg When Caught Between Concrete Forms	C. Trades	Medium	Yes	Pouring Conc	Ties broke off, creating a pinch point for the worker's leg
386	352440	Five Employees Injured When Walkway Collapses	Various	Medium	Yes	Pouring Conc	Improper walkway installation, metal hangar missing
387	418300	Five Employees Injured When Concrete Forms Fall	-	Medium	Yes	Pouring Conc	Supporting scaffold collapse caused forms to collapse, reason unspecified
388	352440	Two Iron Workers Injured By Falling Concrete Floor Slab	Various	Medium	Yes	Other	Precast panel fell while adjustments
389	830500	Employee Killed In Fall From Bridge Pier	-	High	Fatality	Erection	Improperly secured lanyard came loose, causing fall
390	950411	Construction Employee Killed In Fall From Rebar Cage	Supervisor	High	Fatality	Erection	Form fell on worker and broke safety chains, striking the worker and causing him to fall
391	854910	Employee'S Leg Fractured By Crane Load	Carpenter	Medium	Yes	Erection	load swung onto worker's leg and fell on it
392	1032500	1 Construction Worker Killed, 2 Injured When Crane Boom Fell	-	High	Fatality	Stripping	Boomlne broke, causing left hand pendant line to decapitate worker

	Report ID	Event Description	Trade	Severity	Hospitalized/Not	Activity	Cause
393	453710	Employee Injured In 51 Ft Fall Due To Defective Rigging	C. Trades	Medium	Yes	Transportation	Crane hook detached from form, causing it to fall along with worker
394	454510	Employee Killed In Fall From Concrete Formwork	Finisher	High	Fatality	Other	Fall from unguarded platform, w/o fall protection
395	626300	Employee Crushed When Crane Operator Dropped Form Onto Him	-	High	Fatality	Transportation	Crane Operator's field of vision was restricted and no signalperson was present
396	854910	Employee Injured When Struck By Falling Concrete Form	Carpenter	High	Yes	Stripping	Brace was removed, causing form to twist and fall on worker
397	626300	Employee Killed In 24 Ft Fall From Deck Overhang	-	High	Fatality	Pouring Conc	Fall from unsupported platform
398	521700	Employee Killed When Struck In Head By Pipe	C. Trades	High	Fatality	Other	Pipe whipped around 9 ft and hit employee, cause unspecified
399	419400	Two Employees Injured In Fall From Collapsing Form Work	-	Medium	Yes	Stripping	Forms fell off bridge pier, cause unspecified
400	418100	Three Employees Injured As Stairway Collapses	-	Medium	No	Other	Unsecured staircase collapsed, after shoring and formwork was removed
401	420600	Employee Killed In 30 Ft Fall Through Floor Opening	-	High	Fatality	Stripping	Worker fell through unguarded opening on floor, caused by inattention
402	352420	Employee Crushed And Killed By Collapsing Concrete Slab	Mason	High	Fatality	NS	Improperly supported slab collapsed
403	521700	Employee Struck In Leg And Hip By Falling Steel Cylinder	C. Laborer	High	Fatality	NS	Pipe used as form fell from crane hook, cause unknown
404	420600	One Employee Killed, Two Injured When Overloaded Crane Fails	-	High	Fatality	Stripping	Form stuck to the structure, causing crane overload
405	627700	Employee Killed When Struck By Falling Concrete Wall Panel	-	High	Fatality	Other	Unsupported precast panel fell down, crushing worker
406	854910	Employee Injured In Fall From Stairway Compartment	Carpenter	Medium	Yes	Stripping	Worker lost grip and fell while moving
407	453710	Two Employees Injured By Falling Debris	Metal Worker	Medium	Yes	Other	Form fell on the floor, causing debristo strike the workers on the stairs
408	625700	Two Employees Killed, Five Hurt In Fall While Shoring Fails	-	High	Fatality	Pouring Conc	Improper installation of shoring system
409	627700	Employee Killed When Struck By Concrete Box Culvert	-	High	Fatality	Assembly	Section of box culvert came loose and struck employee

	Report ID	Event Description	Trade	Severity	Hospitalized/Not	Activity	Cause
410	626600	One Killed, One Injured By Collapsing Concrete Form	-	High	Fatality	Forming	As bolts were removed to adjust width of form, it collapsed inwards
411	355114	Seven Employees Injured When Concrete Slab Collapses	Various	Medium	Yes	Pouring Conc	Scaffolding failure, reason unspecified
412	552700	Employees Injured When Floor Collapses	Finisher	Medium	Yes	Pouring Conc	Deck form collapse, reason unspecified
413	418800	Employee Killed By Falling Crane Boom	-	High	Fatality	Pouring Conc	Falling crane boom, reason unspecified
414	352440	Employee Sustains Fracture From Fall	Carpenter	Medium	Yes	NS	Lost balance and fell, with equipment
415	854910	Employee Injured When Hit By Falling Piece Of Plywood	-	Low	No	Stripping	Worker was removing shoring supports when the unsupported plywood fell
416	854910	Employee'S Leg Broken When Pinned By Dirt	Finisher	Medium	Yes	Stripping	Removal of brace caused dirt to roll down and pin wprker's leg
417	352440	Four Employees Injured When Concrete Formwork Collapses	Various	Medium	Yes	Pouring Conc	Improperly braced and design formwork
418	626300	Employee Killed In Fall While Removing Forms	-	High	Fatality	Stripping	Worker was working at an unguarded area w/ a safety belt, but no lanyard
419	552700	Struck By Falling Steel Form	Carpenter	High	Yes	Erection	No bracing and loose supports
420	521400	Employee'S Leg Fractured By Falling Crane Boom	-	Medium	Yes	Pouring Conc	Bolt sheared off, causing boom to fall on employee
421	418300	Employee Killed When Struck By Falling Formwork	-	High	Fatality	Other	Worker started work thinking stripping was over
422	625400	Employee Killed In Fall From Bridge	-	High	Fatality	Erection	Lack of training and fall protection
423	316700	Employee Killed In Fall From Wall	-	High	Fatality	Pouring Conc	An attempt to pass the concrete hose knocked worker off balance
424	854910	Employee Fractures Shoulder In Fall From Concrete Form	Carpenter	Medium	Yes	Forming	Fell though unguarded hole
425	112300	One Employee Killed, Two Injured When Floor Collapses	-	High	Fatality	Pouring Conc	Formwork collapse, reason unspecified
426	950411	Employee Injured When Crane Tipped Over	-	Low	No	Transportation	Crane was used beyond capacity
427	625400	Eight Injured When Floor Collapses During Construction	-	Medium	Yes	Pouring Conc	Inadequate lateral support for the joists/shoring

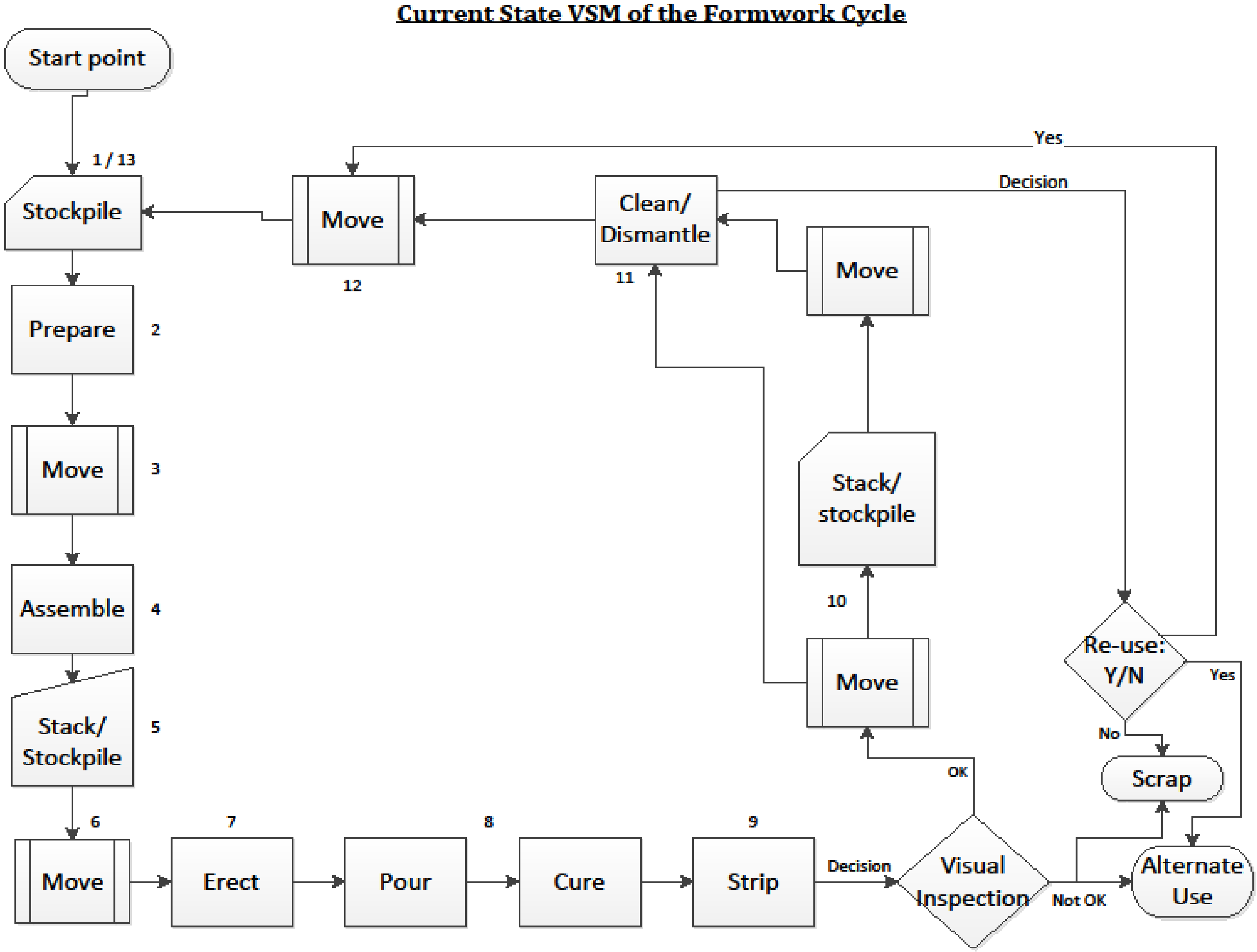
	Report ID	Event Description	Trade	Severity	Hospitalized/Not	Activity	Cause
428	352420	Fall From Elevation By Employee Who Landed On A Piece Of Reb	Supervisor	High	Yes	Erection	Uncapped rebar, no mention of fall protection
429	418800	One Killed, Seven Injured, When Formwork System Fails	-	High	Fatality	Pouring Conc	Inadequately designed formwork system, w/o adequate diagonal and lateral bracing
430	854910	Employee Injured In Fall While Removing Wall Forms	C. Trades	Medium	Yes	Stripping	The 2x4 to which his lanyard was hooked to swung out when the bracket was removed
431	950411	Employee Injured In 28 Ft Fall Through Floor Opening	-	High	Yes	Stripping	Worker fell through unguarded opening trying to prevent form from falling through
432	418800	Employee Injured When Struck By Crane Boom	-	Medium	Yes	Pouring Conc	Manufacturer's instructions disregarded and crane overloaded
433	830300	One Employee Killed, Two Injured, When Building Collapses	-	High	Fatality	Erection	Adjacent building collapsed, reason unspecified
434	953220	Employee Killed In Fall From Scaffold Platform	Finisher	High	Fatality	Pouring Conc	Worker jumped onto a slick, slippery and unguarded Scaffold platform
435	420600	Employee Killed In 104 Ft Fall From Concrete Form	-	High	Fatality	Assembly	Worker fell off an aluminum purlin, no fall protection was used
436	626300	One Employee Killed, One Injured When Struck By Falling Form	-	High	Fatality	Stripping	Form broke loose during attempts to release it, causing it to fall
437	854910	Two Employees Injured When Struck By Scaffold, One Falls	Carpenter	Low	No	Erection	Mobile scaffold tipped due to drain hole and fell
438	854910	Employee Injured In Fall From Formwork	Carpenter	Medium	Yes	Erection	A piece of formwork on which worker was standing slipped

APPENDIX – III A: SAFETY RISK SURVEY

Safety Survey

The purpose of this study is to assess the safety risk associated with different activities during one use cycle of formwork**. Please note that the information you provide will be kept completely confidential, and is only used to assess potential hazards that could cause harm.**

This questionnaire focuses on the various steps that constitute one formwork cycle by identifying major activities as per the diagram below. The fields that require your response have been highlighted.



<u>Steps for completing the survey:</u>

1. Verify that the listed activities are commonly performed when using formwork. If applicable, make any notes about modification or changes in the activities in the spaces provided at the bottom of the table. Please note any special factors for any activity that either increase or decrease risk of worker injury.
2. Each project may have its own formwork cycle, which may not contain all the steps shown/listed. If so, please indicate that the activity is not performed by putting a zero (0) in the "Activity Exposure" field.
3. For the "Activity Exposure" fields, please indicate the percentage of time spent on each activity. The different percentage values may add up to more than 100%, if work is done simultaneously.
4. For the "Injury Severity Level" fields, using your experience and judgment, indicate, for a single worker or work crew, "how frequently an injury occurs at each severity level while performing each construction activity" using the following frequency scale for filling in your responses:

Frequency Scale: Average amount of time between incidents per worker										
Impossible	Negligible	50 years	10 years	5 years	1 year	6 months	1 month	1 week	1 day	1 hr
0	1	2	3	4	5	6	7	8	9	10

The definitions of the severity levels are given as follows:

Severity	**Description****
Near Miss	No work time impact (Incident does not result in harm to the worker)
Low Severity	Less than one day missed work time (Incident results in pain, discomfort, or requires first aid treatment)
Medium Severity	More than one day missed work time (Incident results in lost work time or hospitalization)
High Severity	Worker does not return to work ever (Incident results in permanent disability or death)

<u>NOTE:</u> ******An incident refers to a worker getting injured <u>while working on that specific activity</u>, *i.e.*, direct interface with the design element during all phases of its construction.

A completed sample with explanatory notes is provided for your reference.

<u>Demographic Information:</u>

Your Position/Title	
Name of Organization/Employer	
Years of construction experience	
Type(s) of work experience/Trade(s)	

Activity: **Stockpile/Prepare by cutting into sizes**

0 is never, 10 is very frequent!

ACT. NO.	ACTIVITY EXPOSURE* (%)	ACTIVITIES	ACTIVITY DESCRIPTION	POSSIBLE FREQUENCY OF INJURY (Frequency of injury on a scale of 0 – 10)			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	**20**	Moving	Unloading and carrying plywood/wood/other form components from trucks to stockpile on site	**7**	**5**	**4**	**2**
2	**40**	Preparation	Cutting plywood/2x's into the necessary sizes and shapes required to construct a formwork panel using a handsaw, saw horses, etc.	**9**	**7**	**5**	**3**

NOTE: *Total of all activity exposures may add up to more than 100%

A "near miss" while moving occurs every month for a rating of "7"

Occurrence of a "high severity" injury (disablement or death) during preparation is reasonable, for a rating of "3"

A "medium severity" injury (more than one day missed work) while moving occurs every 5 years for a rating of "4", while for preparation a "medium severity" injury can happen every 1 year with a rating of "5." A lower rating is safer.

Factors that **increase** risk of injury: ___no sawhorses, formwork not banded together___

Factors that **decrease** risk of injury: using a worktable, unloading with a forklift, maintaining safe distance from load__

Table to fill up:

ACT. NO.	ACTIVITY EXPOSURE * (%)	ACTIVITIES	ACTIVITY DESCRIPTION	POSSIBLE FREQUENCY OF INJURY (Frequency of injury on a scale of 0 – 10) *Important- Put in frequency values for all 4 severity levels			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1		Stockpile	Unloading and carrying plywood/wood/other form components from trucks to stockpile on site				
2		Preparation	Cutting plywood/2x's, etc. into the necessary sizes and shapes required to construct a formwork panel using a handsaw, etc.				
3		Moving (Optional)	Carrying components to a work spot, where forms can be assembled				
4		Assembling forms	Assembling a formwork panel using the prepared components, nails, nail gun, clamps, brackets, etc.				
5		Stacking Prepared forms	Stacking assembled panels manually or with a forklift until they can be placed.				
6		Moving	Carrying assembled panels to the spot where they are to be erected and used, possibly at a height requiring fall protection.				
7		Erection or Placing Forms	Process of putting up the forms, installing snap ties, stakes, shoring, rebar, Falsework, etc., possibly at a height requiring fall protection.				
8		Pouring Concrete/ Curing	Pouring concrete, compacting it using vibration (or any other means), and letting the placed concrete cure, possibly at a height requiring fall protection.				

9		Stripping forms	Removal of forms and supporting falsework after the required curing time, possibly at a height requiring fall protection.				
10		Move forms	Moving the stripped formwork panels to a stockpile/work area after stripping.				
11		Dismantling/ cleaning forms	Replacing damaged parts of the panel or dismantling the panels to its components, cleaning concrete or other debris from the forms, oiling forms, and repairing the surface of the forms if necessary.				
12		Move form components/ forms	Move the formwork panels/ formwork components in order to stockpile them or use them again in the next formwork use cycle.				
13		Stack/Stockpile forms	Stack up formwork panels or components manually or by using a forklift.				

NOTE: ***Total of all activity exposures may add up to more than 100%**

Factors that **increase** risk of injury: ____

____

Factors that **decrease** risk of injury: ____

____

APPENDIX – III B: SUMMARY OF REPONSES FROM SAFETY RISK SURVEY

For activities 1 to 7:

Color code					
	Activity Exposure	Near Miss	Low Severity	Medium Severity	High Severity

Activity	1. Stockpile					2. Preparation					3. Moving (Optional)					4. Assembling Forms					5. Stacking Prepared Forms					6. Moving					7. Erection/Placing Forms				
Survey # 1	5	2	6	2	2	15	2	8	3	2	10	2	8	3	2	10	2	8	3	2	5	2	8	3	2	10	2	8	3	2	15	2	8	3	2
Survey # 2	5	6	4	3	1	20	2	2	2	1	10	4	3	3	2	30	6	4	3	1	10	3	4	2	1	15	3	4	2	1	20	5	3	2	1
Survey # 3	20	6	4	3	1	30	5	4	3	0	20	7	5	4	2	25	3	2	1	0	25	7	3	3	0	15	5	4	3	1	30	7	5	3	2
Survey # 4	15	7	7	2	2	40	9	8	3	2	50	9	9	2	2	50	8	7	4	3	10	4	3	2	1	5	3	2	2	1	40	4	3	3	2
Survey # 5	20	7	6	5	5	50	6	5	5	4	60	7	6	5	5	70	7	6	5	5	10	6	6	5	5	15	7	6	6	5	50	8	7	6	5
Survey # 6	15	2	2	2	1	40	3	4	2	2	30	6	5	3	2	45	4	4	3	2	10	4	3	3	2	25	6	5	4	3	25	7	6	4	4
Survey # 7	10	4	3	2	1	15	5	4	4	2	20	7	5	3	1	30	6	3	2	1	30	8	7	3	1	15	7	5	4	2	40	5	3	3	1
Survey # 8	20	7	6	5	3	80	6	5	5	3	70	5	4	3	2	50	7	5	4	3	40	6	5	4	3	20	6	5	4	3	50	6	4	3	3
Survey # 9	30	7	6	5	0	50	7	6	5	3	20	7	6	5	0	50	7	6	5	3	20	7	6	5	0	20	7	6	5	2	40	7	6	5	3
Survey # 10	5	1	0	0	0	10	4	2	0	0	15	4	3	2	1	20	3	2	1	0	15	3	1	0	0	20	3	3	2	0	15	3	2	1	0
Survey # 11	15	6	4	3	1	15	7	4	1	0	30	5	3	2	0	15	6	4	2	0	20	3	1	1	0	30	5	1	1	0	50	8	6	5	3
Survey # 12	10	7	5	3	1	10	7	5	3	1	10	9	9	9	9	20	7	5	3	1	5	9	9	9	9	5	9	9	9	10	20	8	6	4	2
Survey # 13	10	6	5	2	1	20	6	5	2	1	5	6	5	2	1	5	6	5	2	1	5	0	0	0	0	20	6	6	6	2	20	6	6	6	6
Survey # 14	5	5	4	3	2	20	8	5	4	1	5	3	4	3	1	20	5	5	4	3	5	3	3	2	1	10	4	3	4	3	20	6	7	6	2
Survey # 15	15	5	4	2	0	15	2	2	5	7	10	3	4	7	2	25	4	4	5	8	10	4	5	4	6	10	2	2	2	3	15	5	5	2	7
Survey # 16	5	8	0	0	0	7	0	2	0	0	4	0	2	0	0	4	0	0	0	0	5	0	0	0	0	10	4	2	0	0	10	6	2	0	0
Survey # 17	4	3	2	1	0	4	5	4	3	1	4	3	2	1	0	20	7	6	5	1	4	3	2	1	0	4	4	3	2	1	4	5	4	3	1

Color code		Activity Exposure	Near Miss	Low Severity	Medium Severity	High Severity

Activity	1. Stockpile					2. Preparation					3. Moving (Optional)					4. Assembling Forms					5. Stacking Prepared Forms					6. Moving					7. Erection/Placing Forms				
Survey # 18	3	3	1	1	1	8	8	5	4	2	1	3	1	1	1	18	6	4	5	1	3	5	2	1	1	1	3	1	1	1	19	8	6	5	3
Survey # 19	10	7	5	3	1	30	9	6	3	2	50	5	5	5	5	25	7	7	8	8	25	9	7	7	6	25	8	8	8	9	25	9	8	7	7
Survey # 20	10	3	3	7	5	20	8	7	8	8	0	0	0	0	0	20	3	4	5	5	5	4	4	5	3	10	7	4	7	7	30	7	7	8	9
Survey # 21	10	4	1	2	0	10	6	2	1	0	20	5	3	1	1	10	4	1	0	0	0	0	0	0	0	10	2	1	0	0	10	3	2	2	1
Survey # 22	10	6	7	4	3	25	7	5	3	3	15	3	2	1	1	20	3	2	2	2	10	2	1	1	1	25	4	3	2	2	40	5	4	3	2
Survey # 23	10	3	6	1	1	10	2	5	1	1	0	1	6	1	1	10	1	1	1	1	20	1	2	4	3	50	2	3	0	0	50	3	3	6	3
Survey # 24	10	0	1	0	0	40	3	7	1	1	30	2	3	3	1	75	8	3	5	6	5	2	4	1	0	50	2	4	2	3	60	5	5	1	3
Survey # 25	20	8	5	4	2	20	8	6	5	2	10	7	3	2	1	30	8	3	2	1	20	8	3	2	1	5	8	3	2	1	50	8	3	2	1
Survey # 26	0	7	4	3	4	80	9	9	4	6	60	5	3	6	2	80	6	7	1	8	60	4	6	2	4	90	3	5	5	6	100	4	4	6	5
Survey # 27	20	6	4	4	3	60	7	6	6	3	70	5	6	3	3	50	7	7	4	3	5	3	3	2	2	5	3	3	3	3	60	7	6	6	6
Survey # 28	0	1	2	1	1	0	5	6	6	3	10	4	5	4	3	40	3	3	3	3	0	4	3	4	4	0	5	4	4	3	90	6	5	5	3
Survey # 29	10	3	3	2	1	50	4	4	3	1	30	5	5	5	2	50	5	5	4	3	50	3	3	3	1	20	6	5	3	2	20	6	5	3	2
Survey # 30	20	7	6	5	4	40	6	3	3	3	10	6	3	3	3	20	3	3	3	3	20	4	4	4	4	5	5	4	4	3	80	5	4	4	3
Survey # 31	10	6	4	3	3	35	5	5	3	3	0	4	3	3	3	15	6	5	3	3	20	6	5	4	3	35	5	5	3	3	65	6	6	4	3
Survey # 32	10	7	5	4	6	20	8	7	6	5	5	6	5	5	5	50	7	6	6	4	5	4	5	5	5	5	4	6	5	6	10	6	5	5	5

For activities 8 to 13:

Color code: Activity Exposure | Near Miss | Low Severity | Medium Severity | High Severity

Activity	8. Pouring Concrete/Curing					9. Stripping Forms					10. Move forms					11. Dismantling/ Cleaning Forms					12. Move forms/ Form Components					13. Stack/ Stockpile Forms				
Survey # 1	10	2	8	3	2	15	2	8	6	2	10	2	8	6	2	10	2	6	6	2	10	2	5	4	2	10	2	6	5	2
Survey # 2	5	3	3	2	1	15	7	5	2	1	10	7	3	2	1	10	6	5	2	1	10	6	5	2	1	10	7	5	2	1
Survey # 3	15	7	5	3	2	20	5	3	2	1	15	7	4	3	1	15	7	5	3	1	20	7	5	3	1	20	6	4	3	1
Survey # 4	10	2	1	1	1	30	9	8	3	2	25	5	4	1	1	10	2	1	1	1	10	2	1	1	1	5	2	2	1	1
Survey # 5	30	8	5	6	7	30	7	6	5	5	10	7	6	5	4	10	7	6	4	3	30	8	7	5	4	20	8	7	6	5
Survey # 6	60	5	5	3	2	25	3	3	2	1	25	4	4	3	1	30	4	4	2	1	30	4	4	3	1	25	4	4	3	1
Survey # 7	5	3	2	1	0	25	6	4	1	0	15	5	3	2	1	15	4	1	1	0	10	3	2	1	0	15	6	3	4	1
Survey # 8	40	5	4	3	3	40	5	5	4	3	20	5	4	3	3	30	4	3	1	1	40	5	4	3	3	40	4	4	2	2
Survey # 9	10	7	6	5	3	30	7	6	5	3	20	7	6	5	0	10	7	6	5	0	20	7	6	5	0	10	7	6	5	0
Survey # 10	15	3	1	1	0	15	4	4	2	1	15	4	3	2	0	10	2	2	1	0	10	2	2	1	0	10	4	2	0	0
Survey # 11	20	1	1	0	0	20	10	9	8	7	5	5	3	2	0	20	7	3	2	1	30	5	1	1	0	30	3	1	1	0
Survey # 12	20	9	9	9	10	10	9	9	9	10	5	9	9	9	10	5	8	9	9	10	5	8	9	9	10	10	9	9	9	10
Survey # 13	10	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0
Survey # 14	5	2	2	2	1	15	6	6	5	2	5	3	2	2	1	5	4	2	2	1	10	4	3	2	1	15	5	5	4	3
Survey # 15	10	4	4	4	4	15	5	3	4	5	20	4	3	2	6	15	3	5	1	4	20	2	3	3	5	20	3	4	4	6
Survey # 16	5	2	2	0	0	10	2	0	0	0	5	4	0	0	0	3	1	0	0	0	8	2	0	0	0	5	2	1	0	0
Survey # 17	10	5	4	3	1	10	5	4	3	1	4	3	2	1	0	4	3	2	1	0	4	3	2	1	0	4	3	2	1	0
Survey # 18	3	6	4	3	2	3	7	5	3	1	1	3	1	1	1	3	6	5	4	2	1	6	5	4	2	3	5	4	3	2
Survey # 19	50	9	7	6	5	25	9	7	5	3	25	8	5	5	5	25	8	6	5	5	25	9	9	5	5	25	9	8	5	5
Survey # 20	16	3	3	5	6	0	7	7	8	9	0	6	6	7	7	0	3	4	4	5	0	4	4	5	5	0	3	3	4	4

Color code		Activity Exposure		Near Miss		Low Severity		Medium Severity		High Severity

Activity	8. Pouring Concrete/Curing					9. Stripping Forms					10. Move forms					11. Dismantling/ Cleaning Forms					12. Move forms/ Form Components					13. Stack/ Stockpile Forms				
Survey # 21	20	9	3	1	1	25	5	4	4	1	5	5	2	1	0	5	7	3	0	2	5	8	3	1	1	10	4	1	1	1
Survey # 22	20	3	2	2	2	20	5	4	2	2	10	2	1	1	1	15	1	1	1	1	10	2	2	1	1	10	2	2	1	1
Survey # 23	10	1	1	1	1	40	6	5	4	3	30	1	3	2	2	0	2	3	4	3	10	1	3	1	2	10	1	3	3	2
Survey # 24	10	4	4	2	3	30	5	2	2	1	20	4	1	1	1	5	1	1	1	1	5	2	1	1	1	5	2	2	1	1
Survey # 25	20	5	2	2	2	40	8	5	4	2	10	5	2	2	2	5	5	2	2	2	10	5	2	2	2	20	5	2	2	2
Survey # 26	20	3	4	7	7	100	4	7	5	8	80	5	4	6	6	100	3	4	7	7	80	4	8	6	8	80	5	6	6	4
Survey # 27	15	4	4	5	4	20	6	5	4	4	5	6	6	4	4	20	3	3	2	2	10	4	4	5	6	30	6	6	7	7
Survey # 28	10	4	3	3	3	90	1	1	1	2	10	1	2	2	1	90	3	3	3	1	10	2	1	1	1	0	2	2	2	1
Survey # 29	0	0	0	0	0	40	7	6	5	5	30	5	4	3	3	10	4	3	2	1	30	4	3	2	1	10	4	3	2	1
Survey # 30	5	3	3	3	3	20	5	4	3	3	10	3	3	3	3	5	3	3	3	3	5	3	3	3	3	5	3	3	3	3
Survey # 31	65	5	6	4	3	40	6	5	5	4	30	4	3	3	3	15	6	6	4	3	20	5	4	4	3	20	6	4	4	3
Survey # 32	10	7	6	6	5	40	7	6	4	5	5	5	4	4	4	40	5	6	7	6	20	5	7	4	6	15	5	6	6	7

Answers to the Open ended questions, and demographics:

Survey #	Position/ Title	Years of Construction Experience	Type(s) of Work Experience/ Trade(s)	Factors that <u>increase</u> risk of injury	Factors that <u>decrease</u> risk of injury
1	Carpenter	10	-	weather, morale, housekeeping, schedule, faulty tools/equipment, material handling	Communication, weather, morale, housekeeping, having the right tool for the job

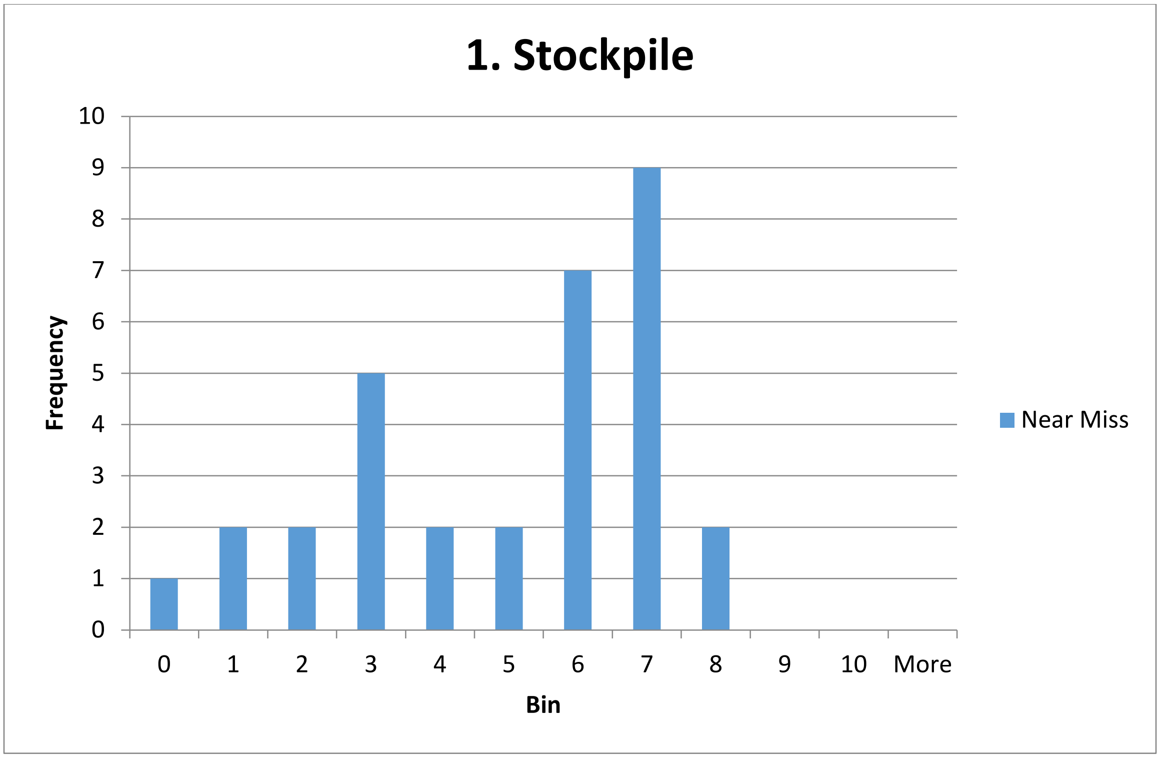
Survey #	**Position/ Title**	**Years of Construction Experience**	**Type(s) of Work Experience/ Trade(s)**	**Factors that increase risk of injury**	**Factors that decrease risk of injury**
2	Carpenter/ Foreman	24	Carpenter	Weather	Communication, Experience, Skill Level
3	Carpenter/ Supervisor	30+	-	Bad Weather, Lack of Space/ Size of Site	Equipment to move forms to location, Good game plan, crew that wrks together (team work)
4	Carpenter	15+	Heavy Construction	Weather- snow, heat, weekend, after work activities	Proper training, Pre-planning, getting our head in the task
5	Journeyman Carpenter	8	Carpentry/ Concrete Forming	weather, lack of proper tools or assembly components, elevation of work, not using safety gear	Equipment (Forklifts, boom lifts, cranes etc.) proper access to where working and use of proper safety gear
6	Carpenter Apprentice	3	-	Weather conditions, tight schedule, equipment failure	Pre-planning, All equipment needed are available (Forklift, Crane etc.)
7	Carpenter Journeyman	20	-	Weather conditions, not trained (e.g. forklift training)	Nice weather, proper equipment and training for workers
8	Project Superintendant	20	Carpentry/ Heavy Concrete	Schedule pressure, wearing proper PPE, proper stretching	Proper lifting techniques, Being aware of your surroundings, proper gloves, safety glasses, not being rushed
9	Superintendant	15	Carpentry	Lack of experience, not paying attention, complacency	Safety Meetings, awareness, knowledge, experience
10	-	-	-	-	-
11	Apprentice	3	Concrete, Roof Framing	Lack of preparation, unskilled, incorrect tools and supplies	Preparation, Skilled labor, Correct tools and supplies
12	Apprentice-3	17	16 residential, 1 Commercial	Weather	Safety Meeting, Proper PPE & Tools
13	Carpenter Foreman	6	Carpentry/ Exterior., Interior	Drinking on the job/ drugs	A good night's sleep
14	Carpenter	24	Residential Remodel, Concrete	Inattention, Hurrying, tight schedule	Planning, Pretask

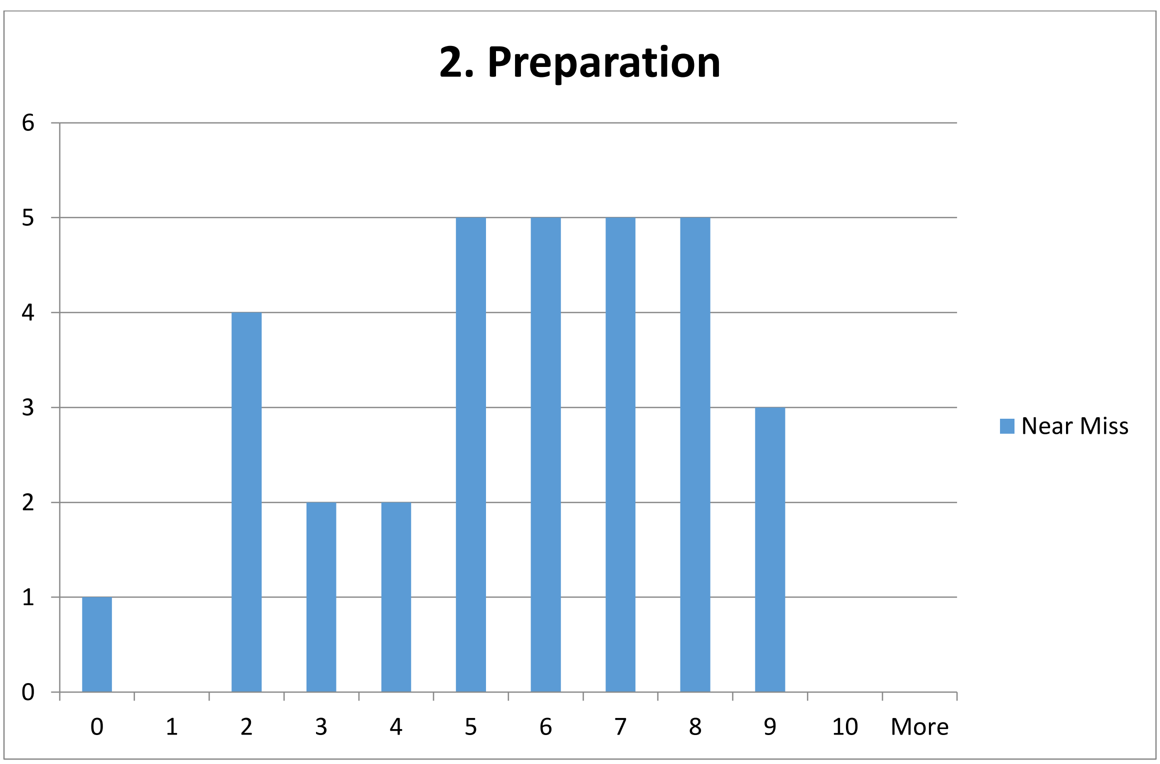
Survey #	Position/ Title	Years of Construction Experience	Type(s) of Work Experience/ Trade(s)	Factors that increase risk of injury	Factors that decrease risk of injury
			Forms		
15	Carpenter	15	Concrete forms, Clean room, data centers, Schools	Being Tired, Complacency, inattention, poor workplace safety plan	Situational Awareness
16	Foreman	29.5	Framing/ Concrete Formwork	Not alert, inexperience	Pre-task planning, well trained personnel, discussion of hazards beforehand
17	-	27	Concrete, Framing, Finishing	No safety program, messy jobsite, debris on the ground, mud, broken tools, lack of concentration, organization and planning	#1 Safety, Clean Job Site, area prepped- gravel flat, no mud
18	Carpenter	41	Filts (?), Metal Framing	Moving unsecured/loose stacks on Forklifts, Swinging large forms into place	Limiting men to 1-2 jobs after linig out safety concerns
19	Carpenter	23	Framing,Concrete forms, Finish Carpentry	Not using Proper lifting techniques	Stretch and Flex using lifting techniques
20	Business representative	36	Carpenter	Moving, setting, and stripping of large forms	Planning
21	Safety Co-ordinator	27	Carpenter	Others do not pay attention to me	-
22	-	42	Carpenter Superintendent	Complacency, unaware of what is going on around us, repetition	Staying Alert
23	Journeyman Carpenter	7	Concrete formwork	Awareness of Environment	Pro-task
24	Carpenter	20	Excavation, Pipe, Conc. Raming, Structural Steel	-	-

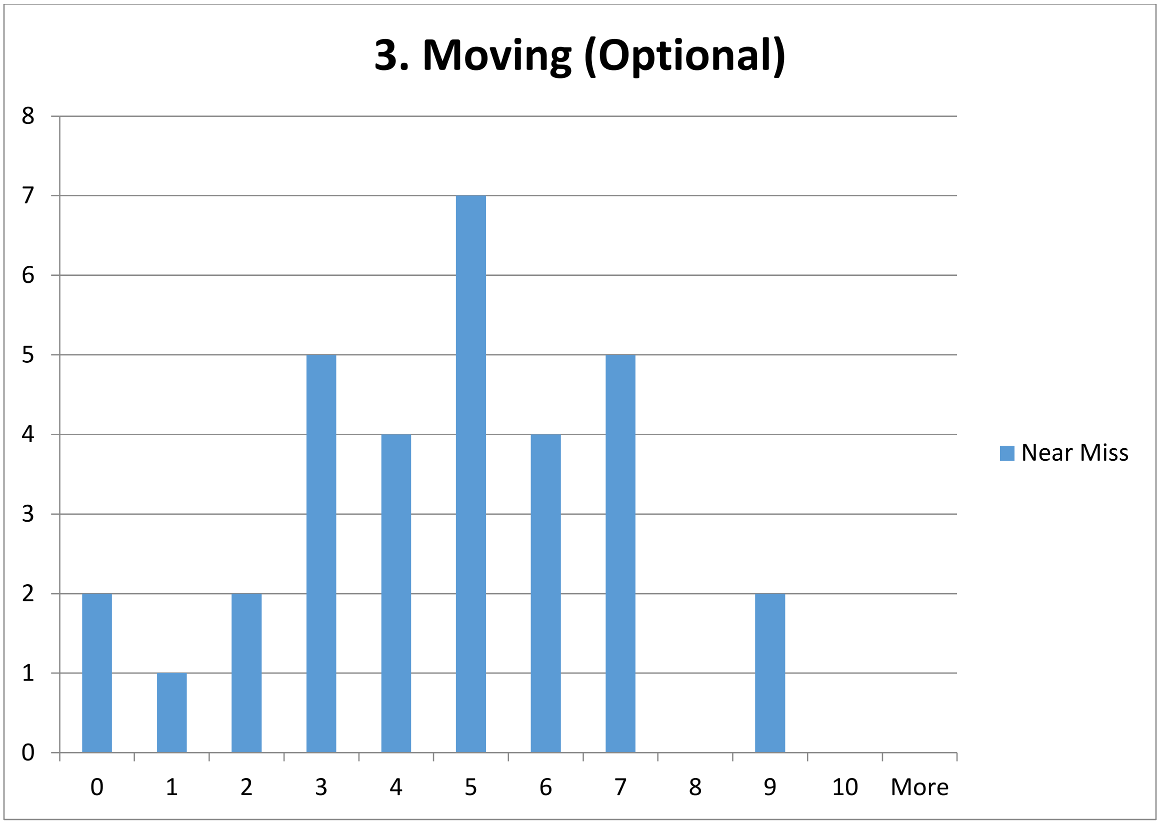
Survey #	**Position/ Title**	**Years of Construction Experience**	**Type(s) of Work Experience/ Trade(s)**	**Factors that <u>increase</u> risk of injury**	**Factors that <u>decrease</u> risk of injury**
25	Journeyman Carpenter	10+	General Construction- Footings to Shingles	Lack of Sleep, Drugs & alcohol, inattention	Sleep, stay sober, no stress, clear mind
26	Lead carpenter	8	Carpenter	-	-
27	Journeyman Carpenter	10	All phases of Construction	Lifting too big for one person, no communication with co-workers	Team work and pre-task
28	Apprentice	4 months	-	-	-
29	Carpenter	15	Concrete formwork, other misc	Heights, weight of material	Well-planned, clean site, materials delivered on time and proper quantities
30	Journeyman Carpenter	11	-	-	-
31	Lead carpenter	11	Structural Concrete	Rain, wind, inexperience, being in a hurry, lack of communication	Proper skills, readily available information and communication, proper tools and material
32	Carpenter	40	Carpenter, Operator	Not Paying attention	Know your surroundings

APPENDIX – III C: HISTOGRAMS TO IDENTIFY APPROPRIATE PDF

Histograms for Near Miss:






3. Moving (Optional)
8
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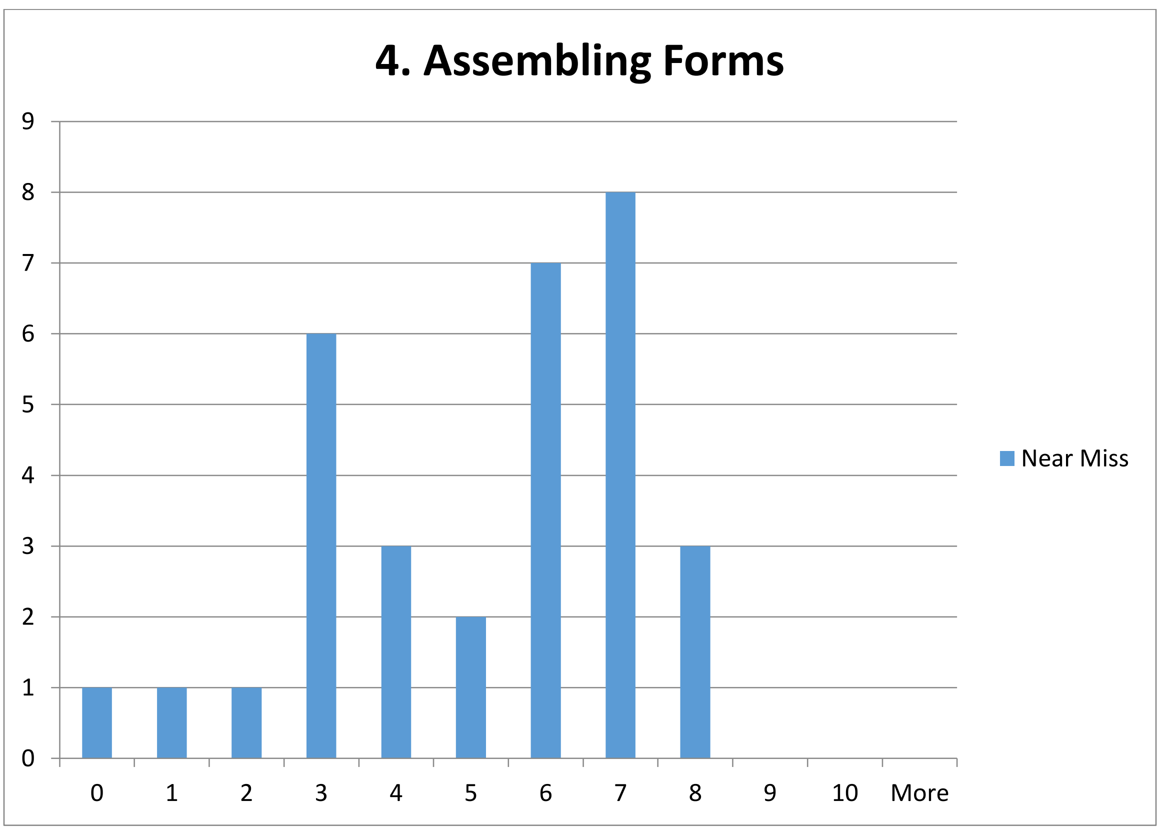
More
Near Miss


4. Assembling Forms
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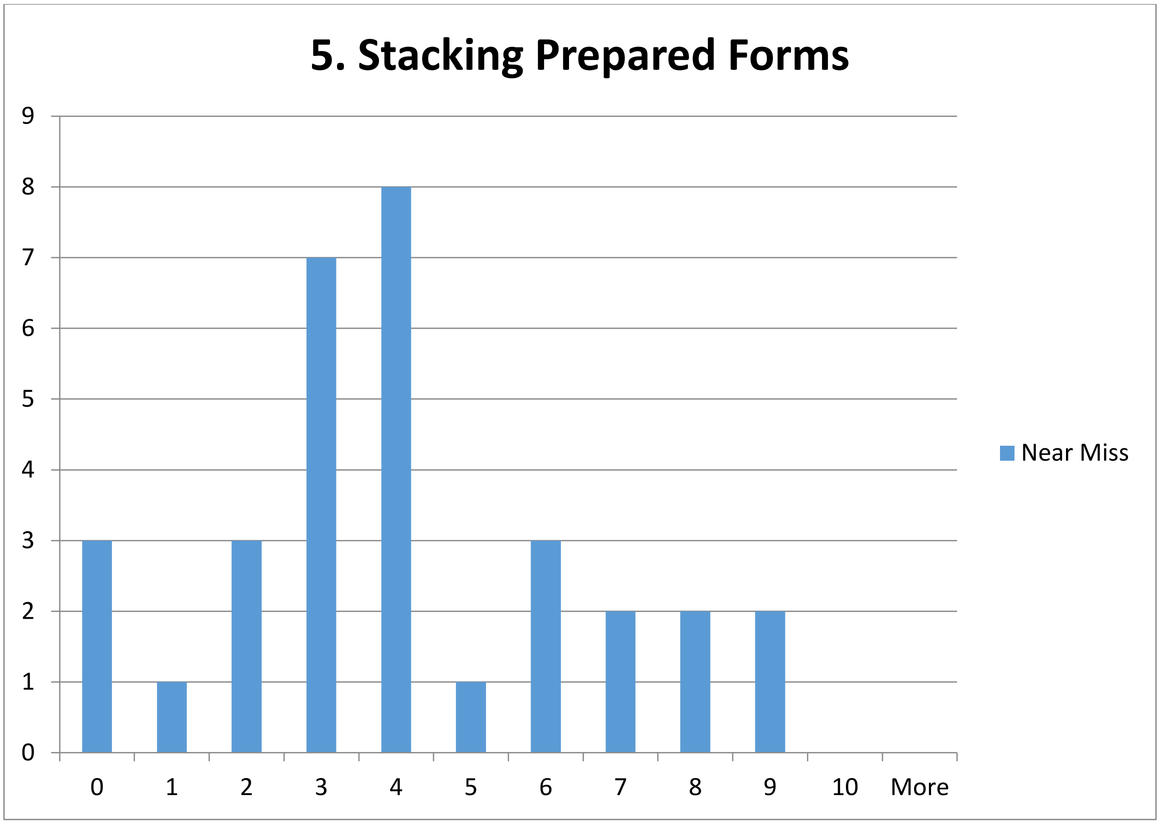
More
Near Miss


5. Stacking Prepared Forms
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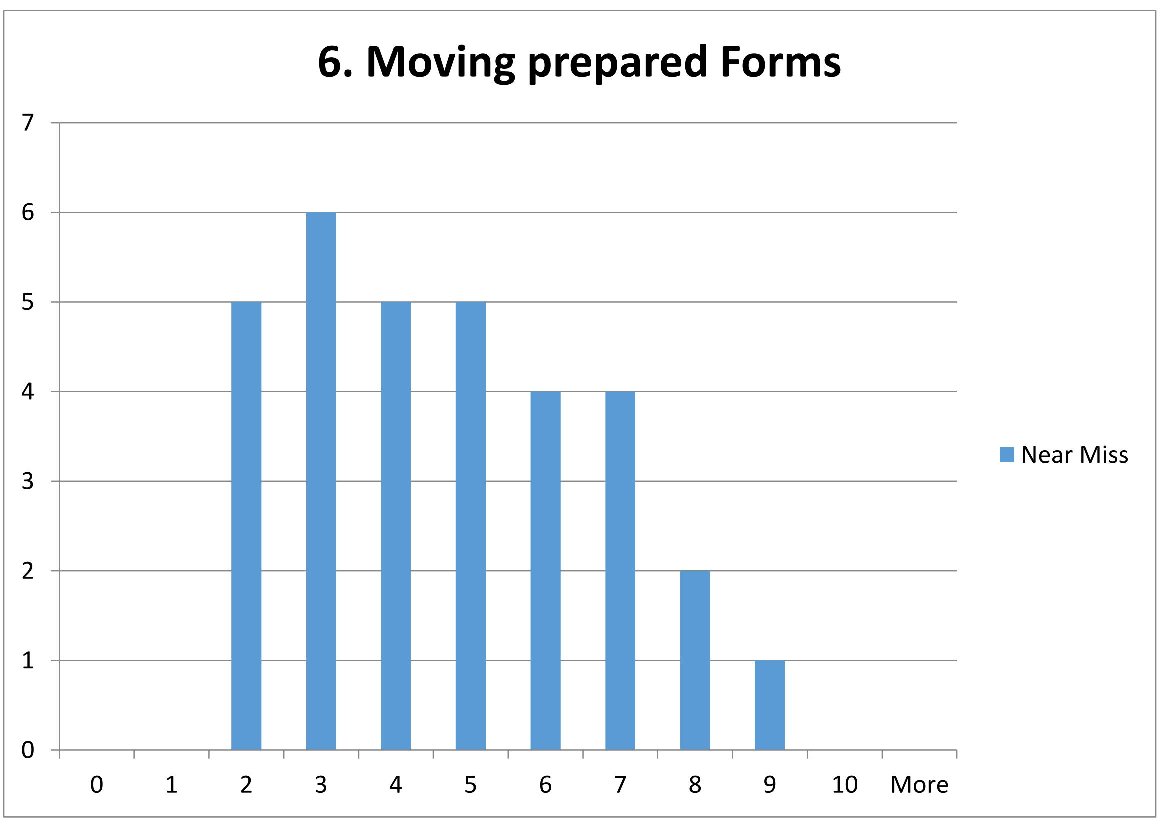
More
Near Miss


6. Moving prepared Forms
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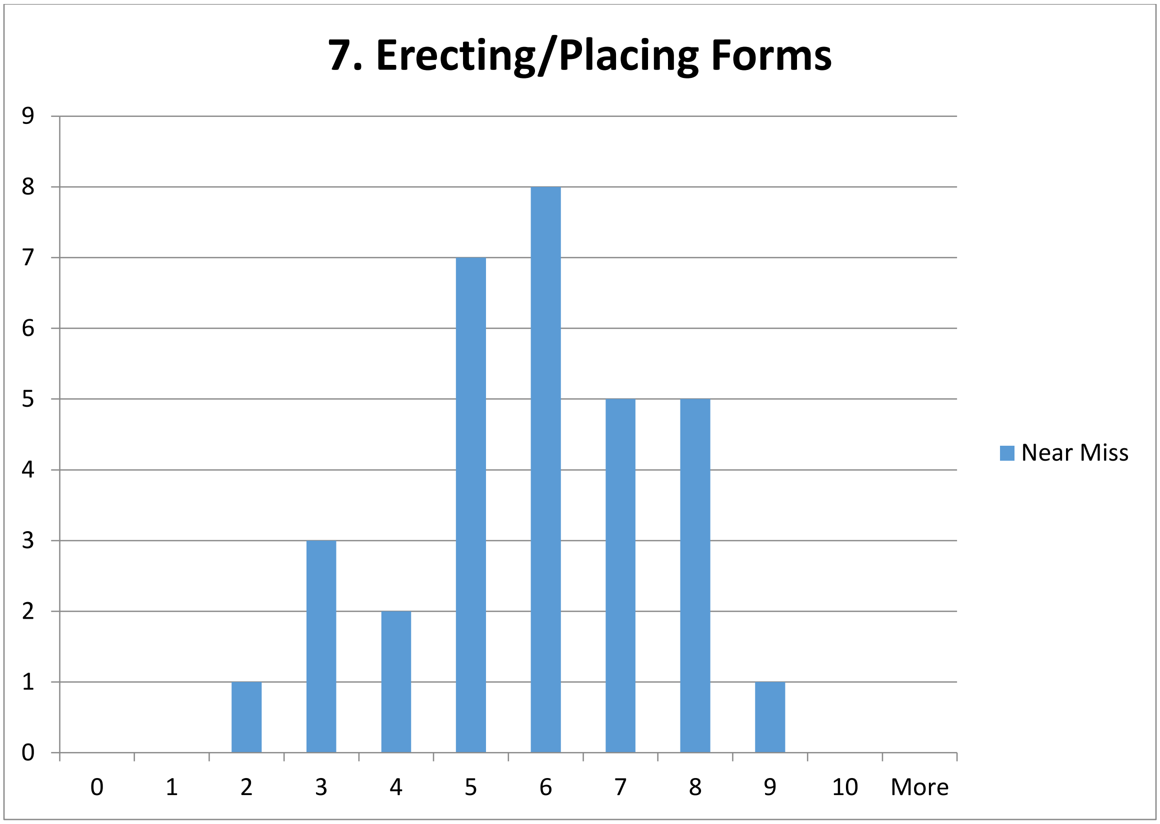
More
Near Miss


7. Erecting/Placing Forms
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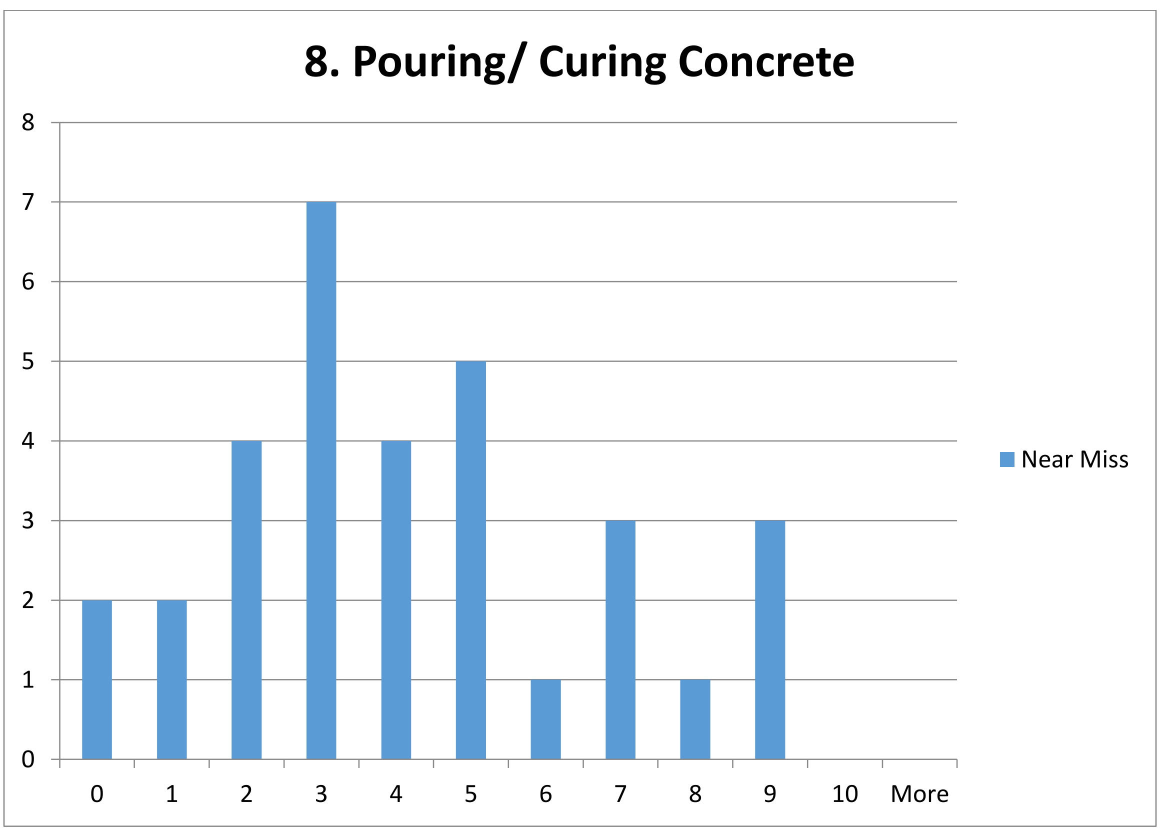
More
Near Miss


8. Pouring/ Curing Concrete
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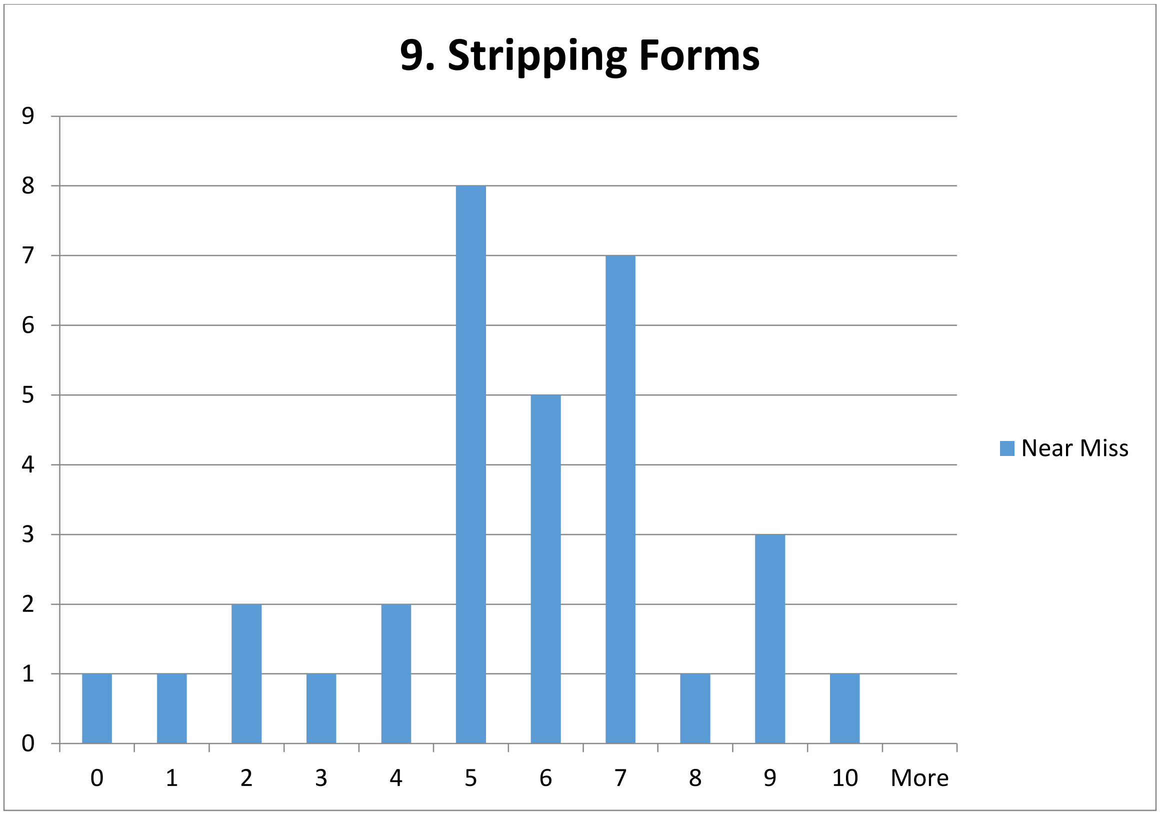
More
Near Miss


9. Stripping Forms
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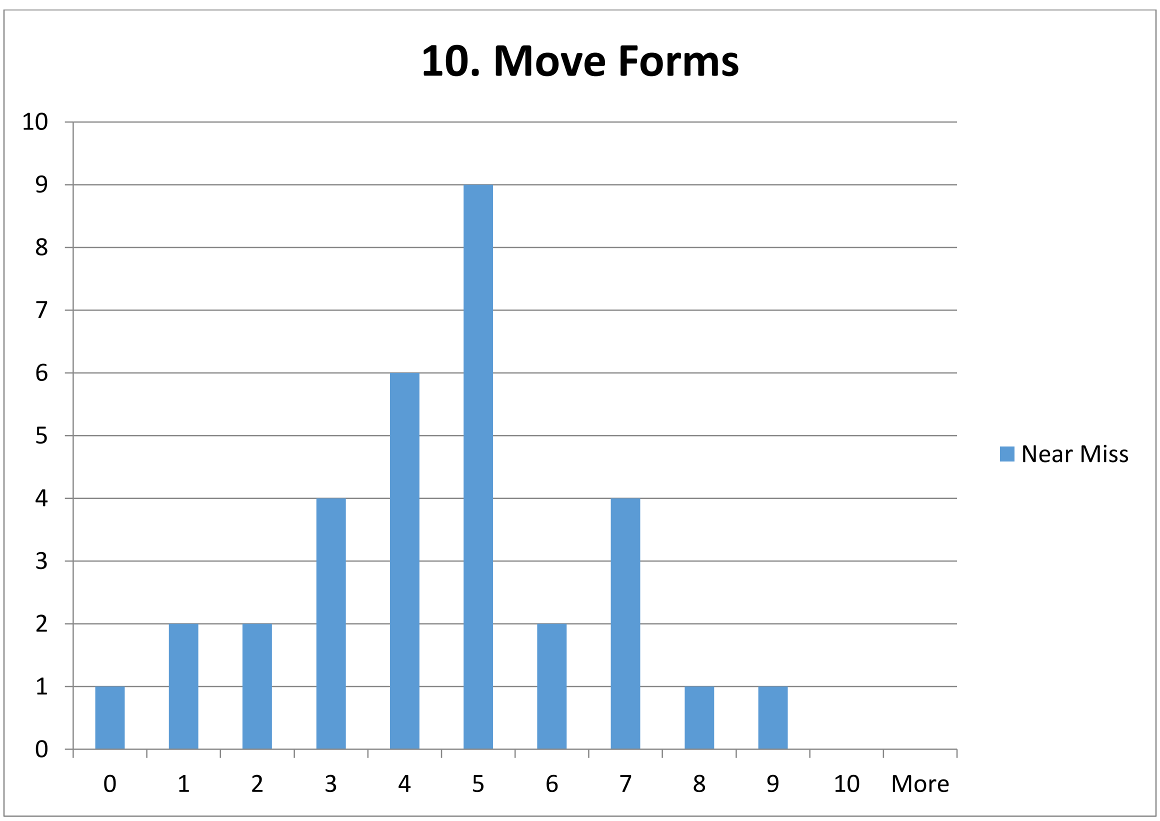
More
Near Miss


10. Move Forms
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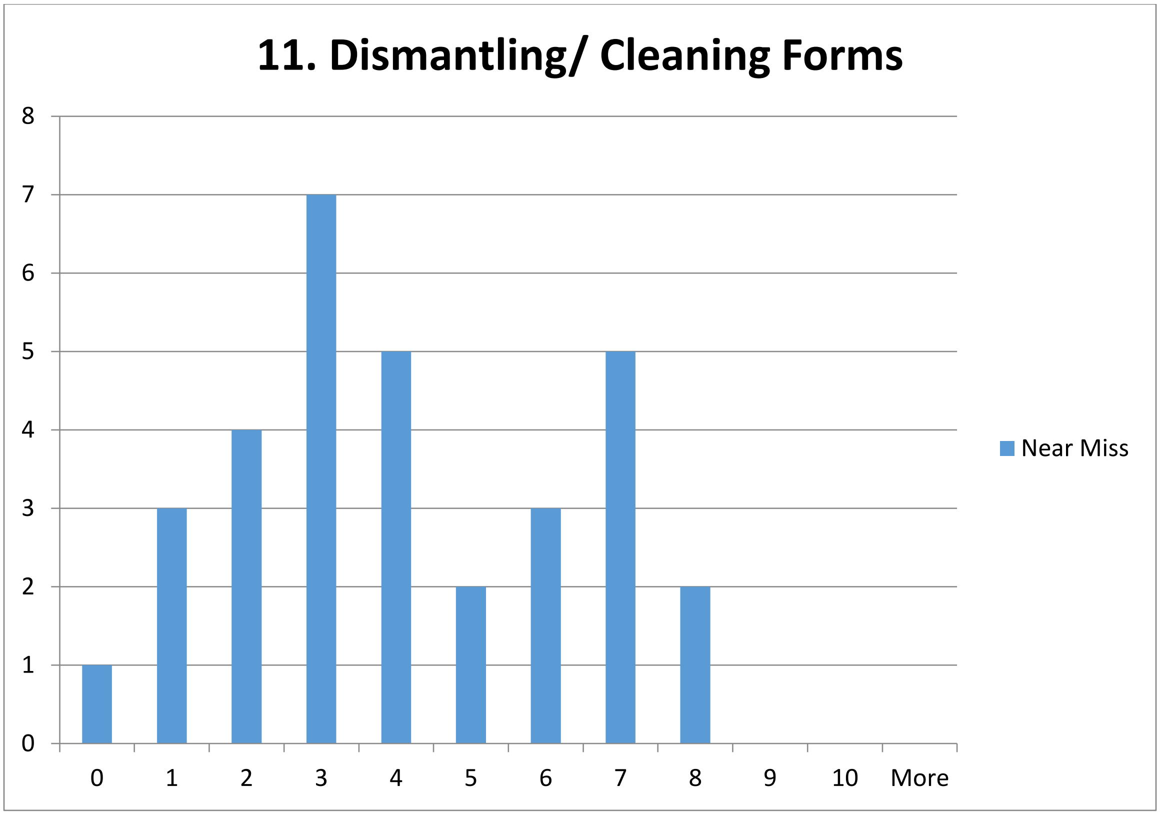
More
Near Miss


11. Dismantling/ Cleaning Forms
8
7
6
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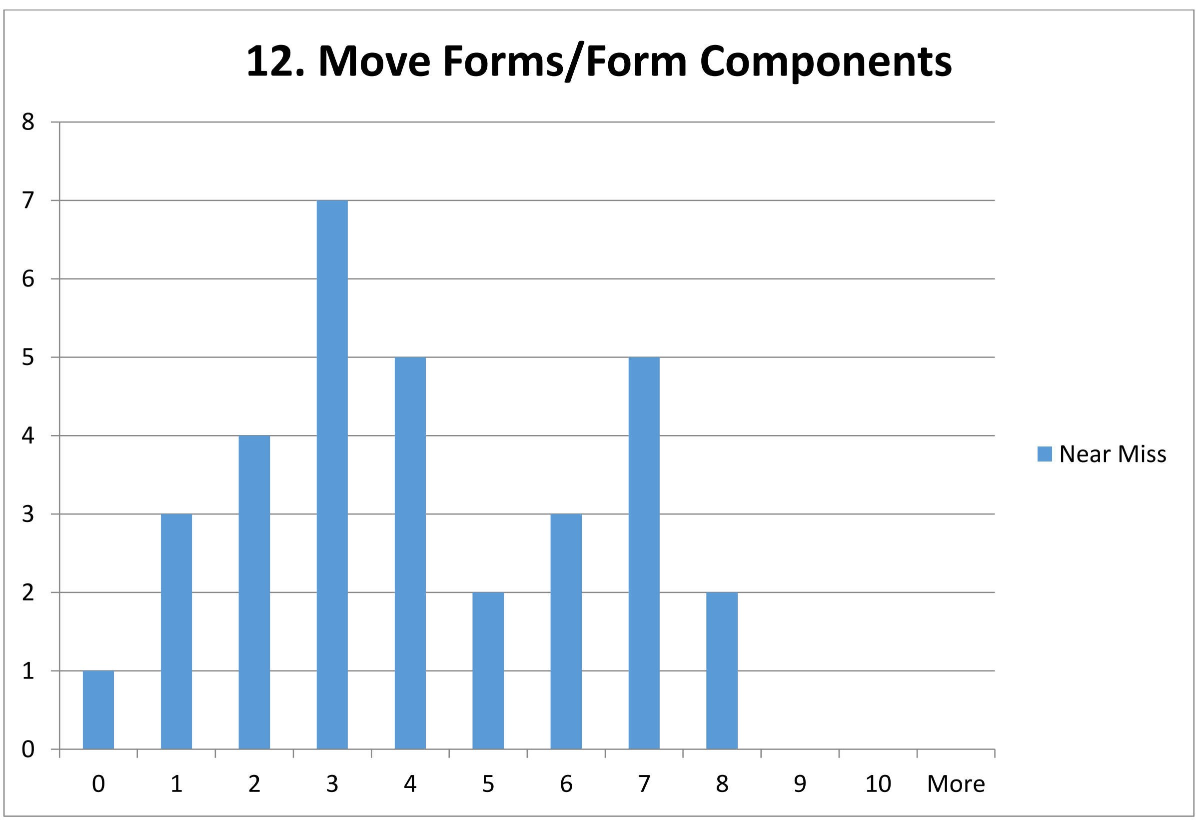
More
Near Miss


12. Move Forms/Form Components
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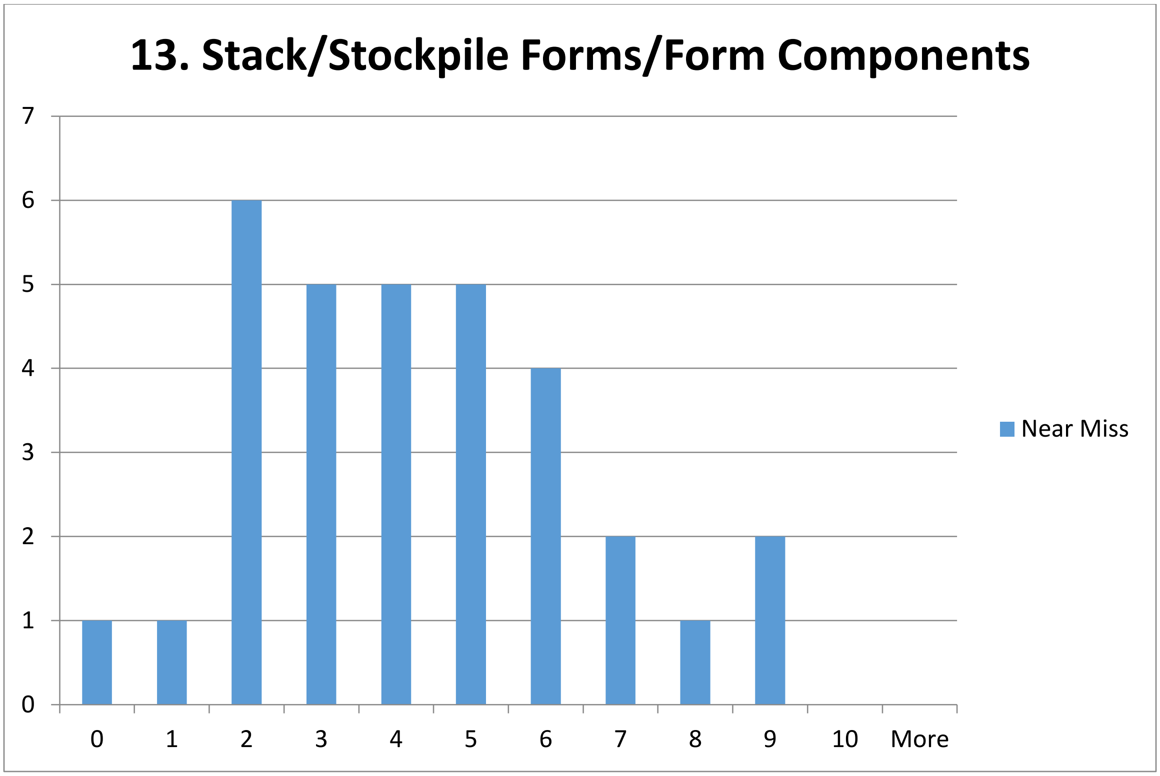
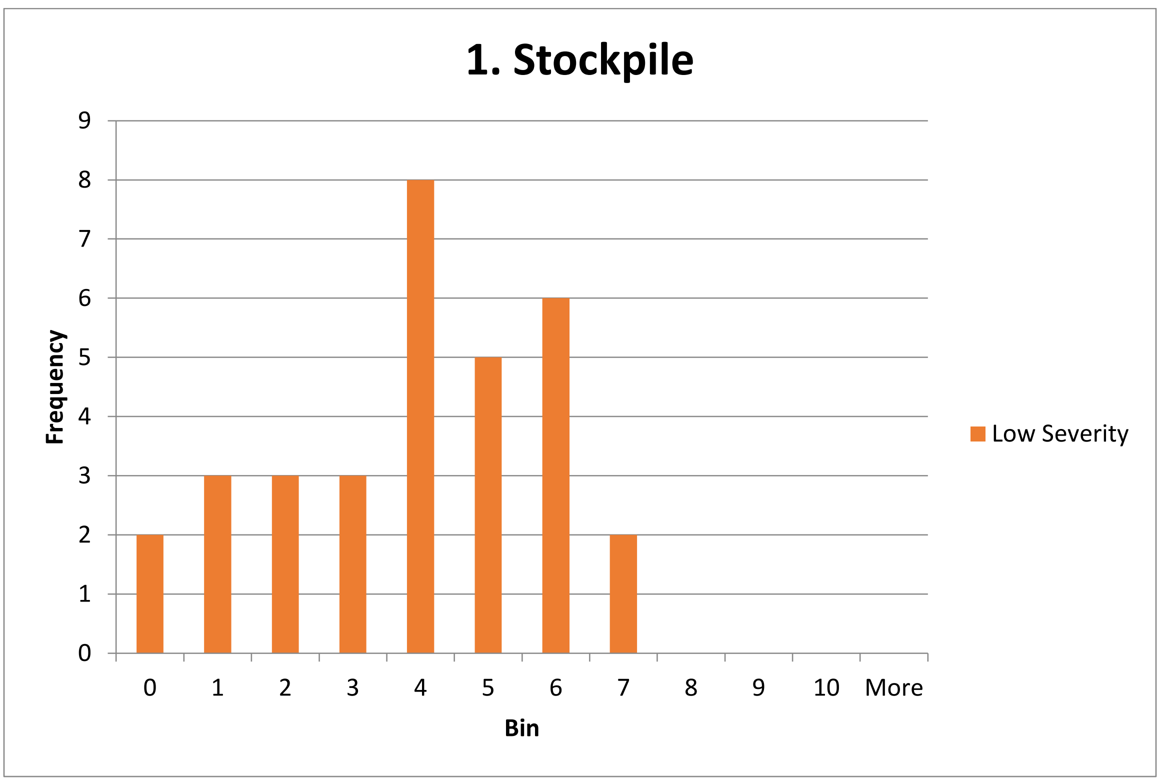
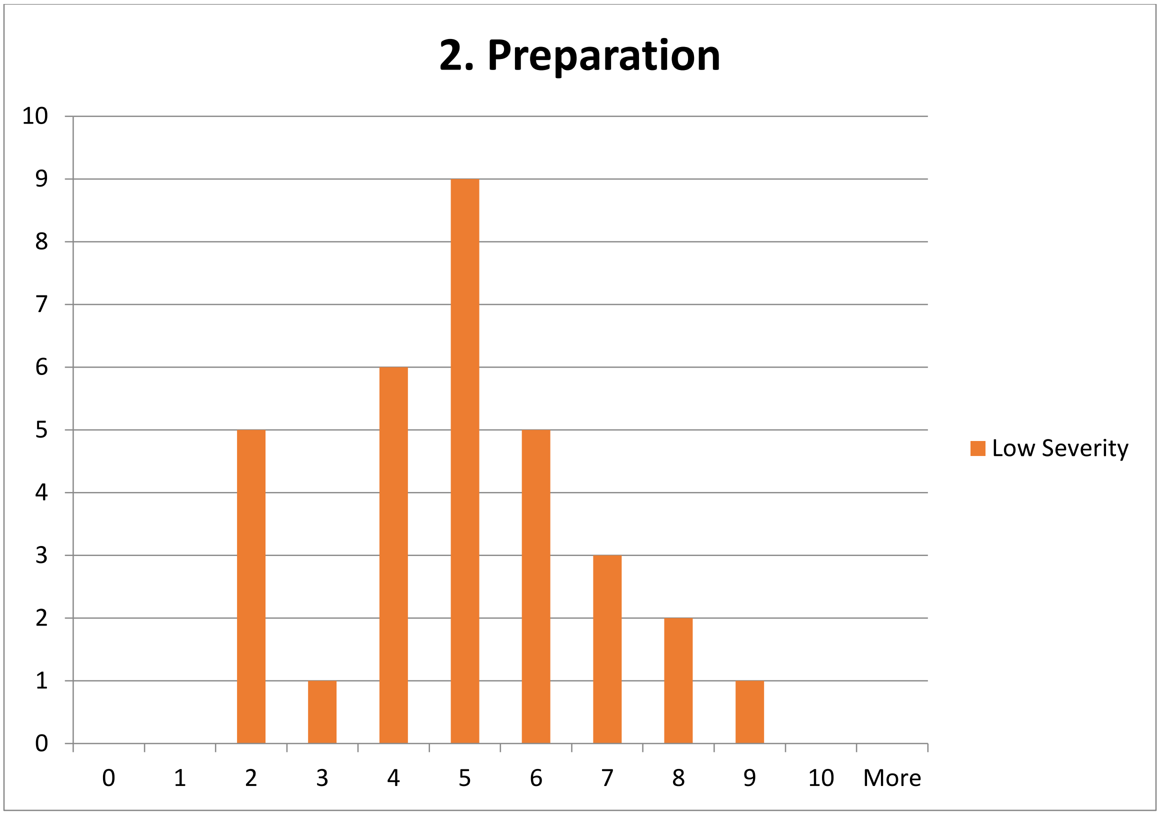
More
Near Miss



Histograms for Low Severity:




2. Preparation
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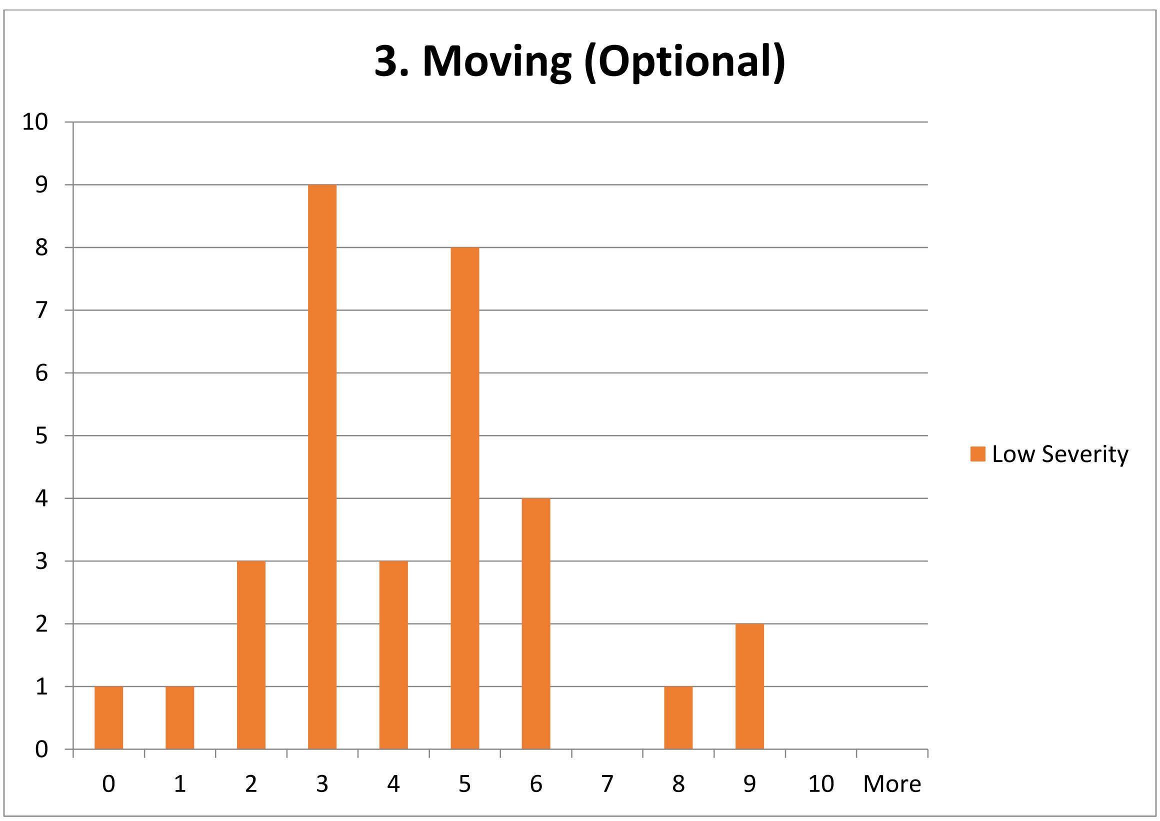
More
Low Severity


3. Moving (Optional)
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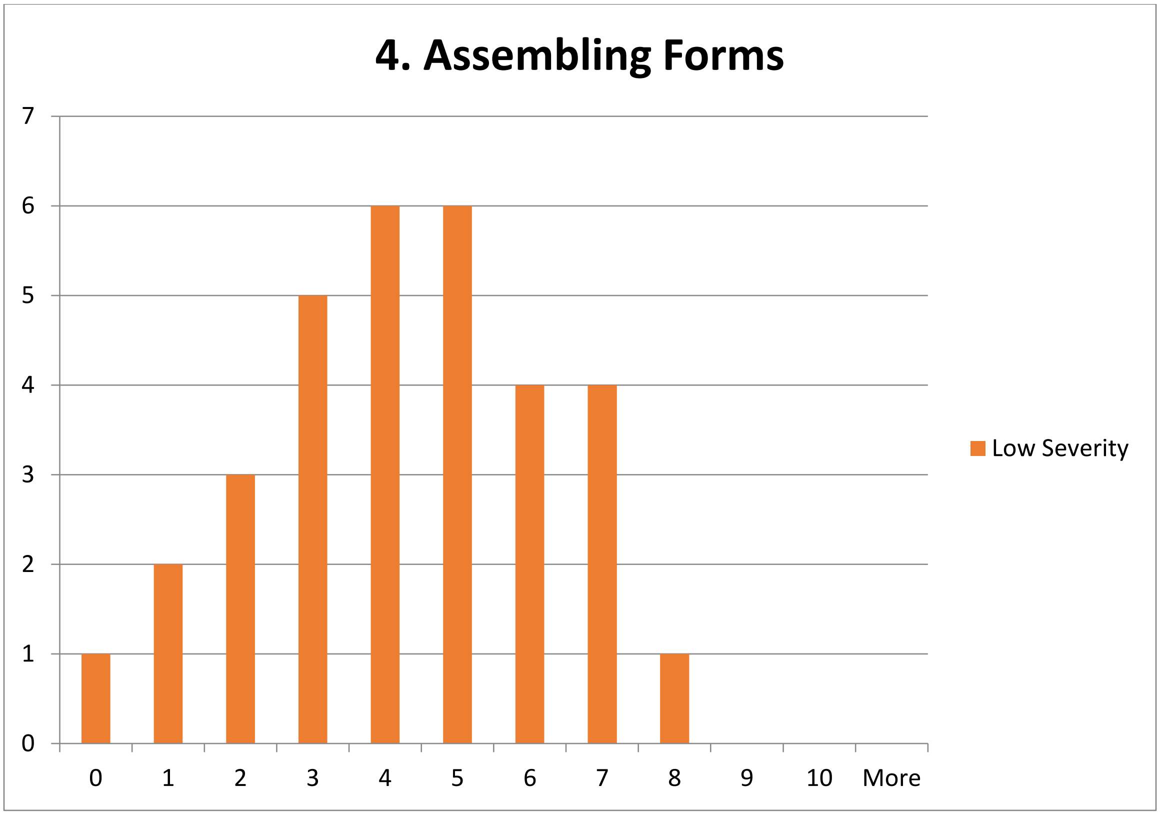
More
Low Severity


4. Assembling Forms
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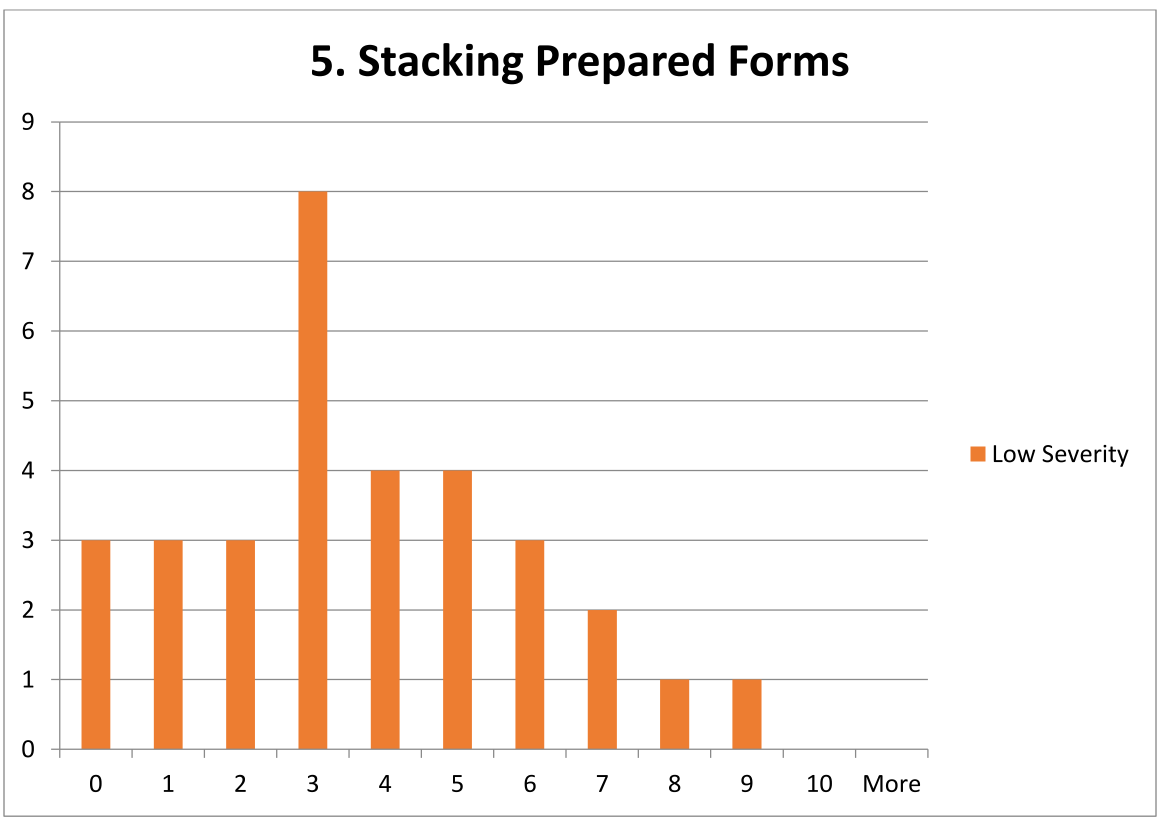
More
Low Severity


5. Stacking Prepared Forms
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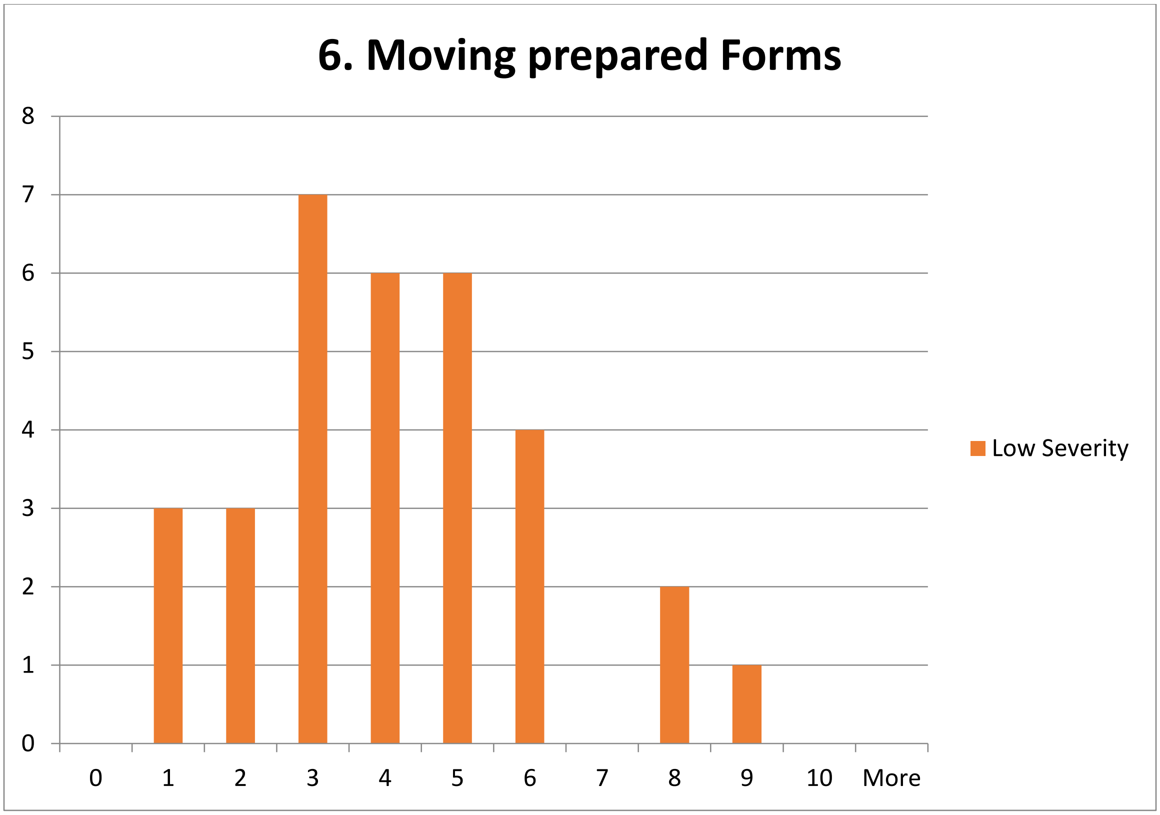
More
Low Severity


6. Moving prepared Forms
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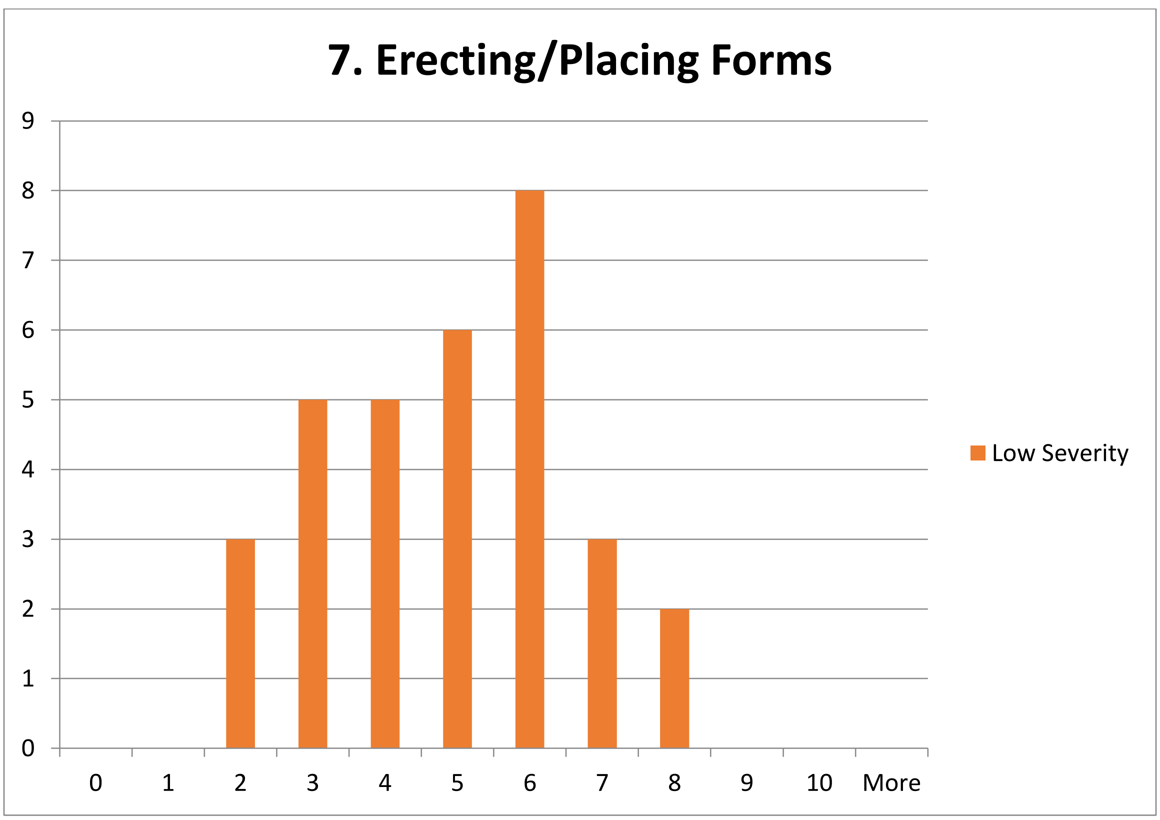
More
Low Severity


7. Erecting/Placing Forms
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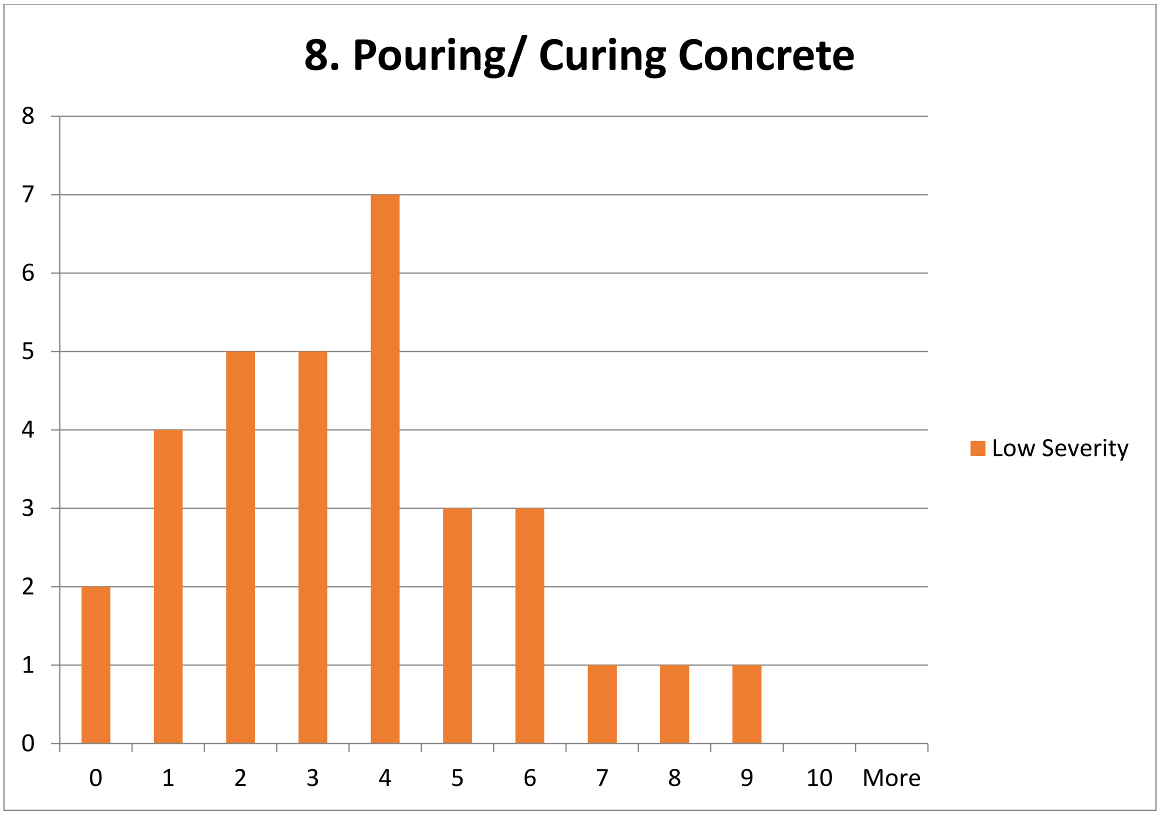
More
Low Severity


8. Pouring/ Curing Concrete
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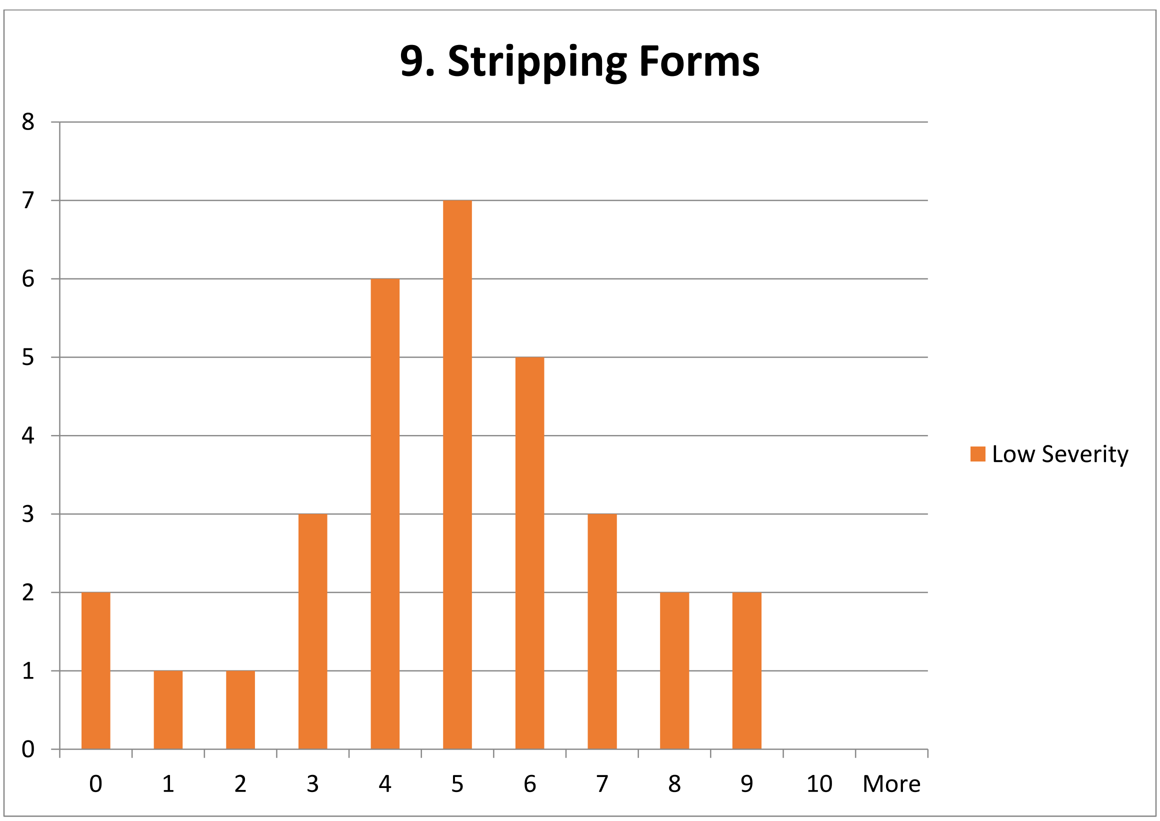
More
Low Severity


9. Stripping Forms
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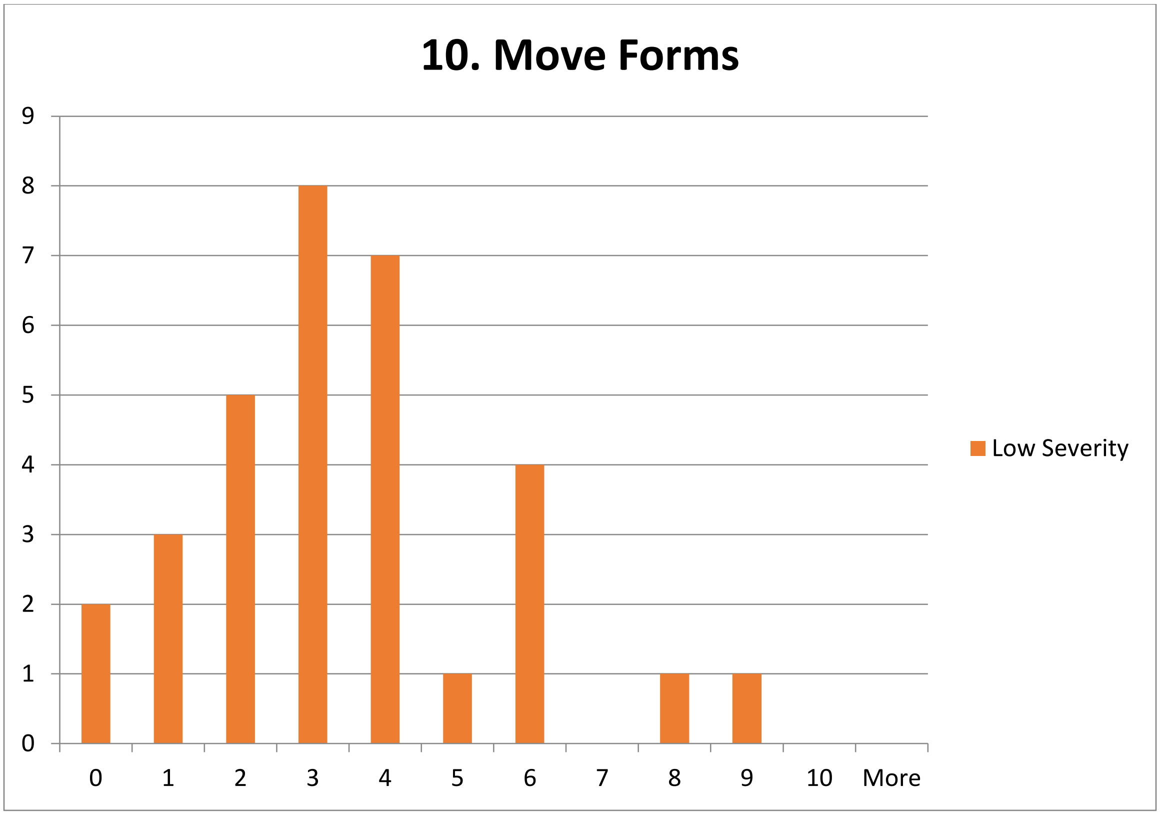
More
Low Severity


10. Move Forms
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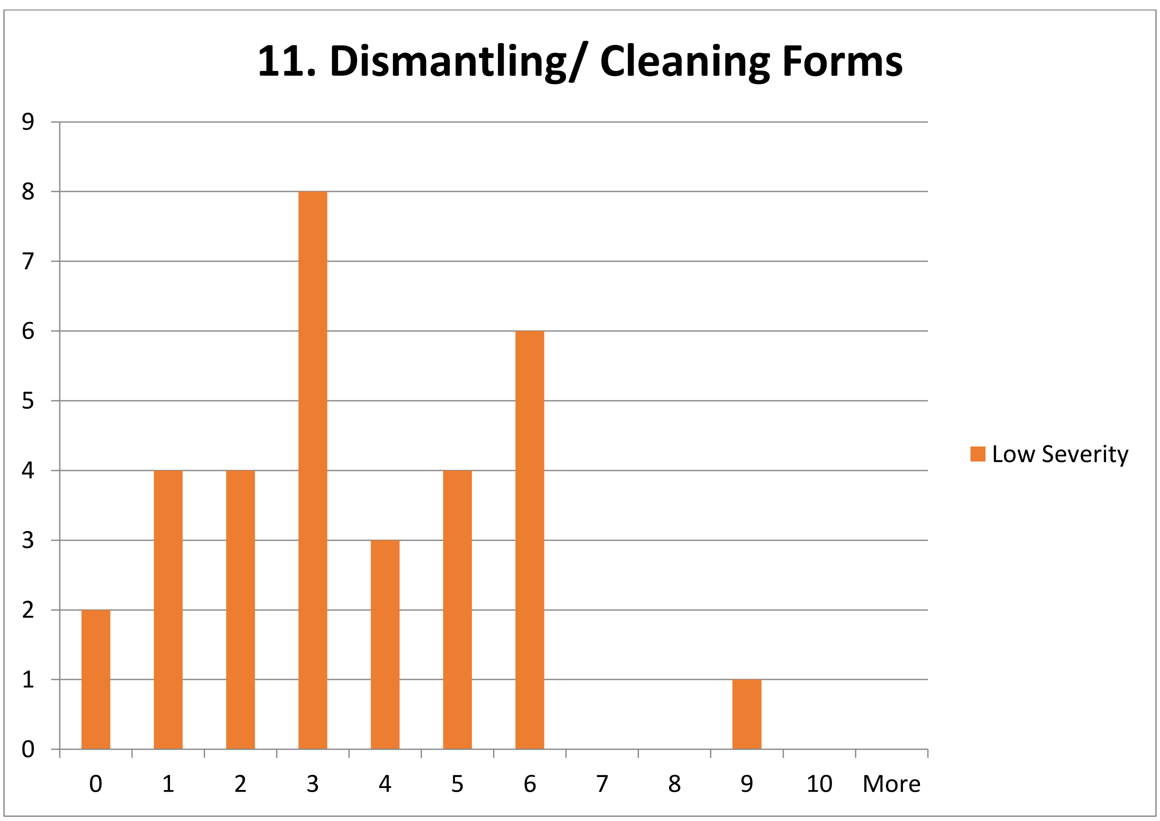
Low Severity


11. Dismantling/ Cleaning Forms
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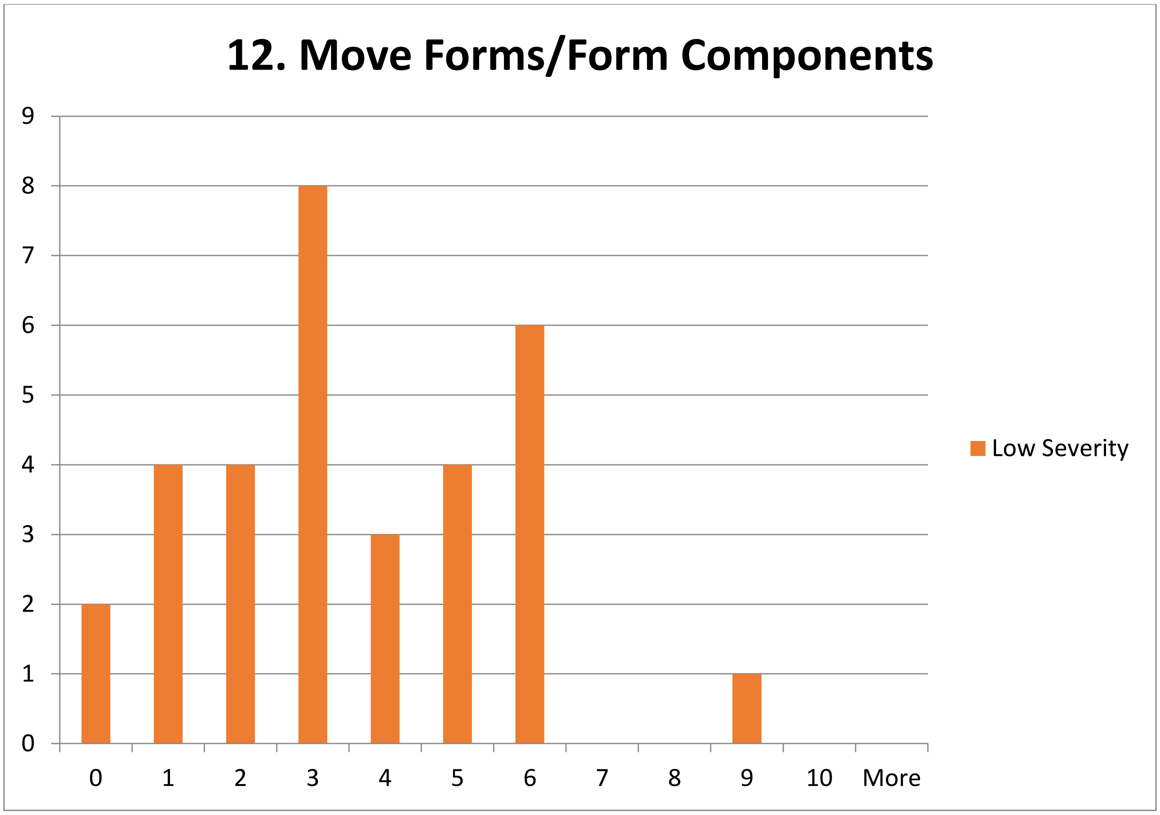
0 1 2 3 4 5 6 7 8 9 10 More
Low Severity


12. Move Forms/Form Components
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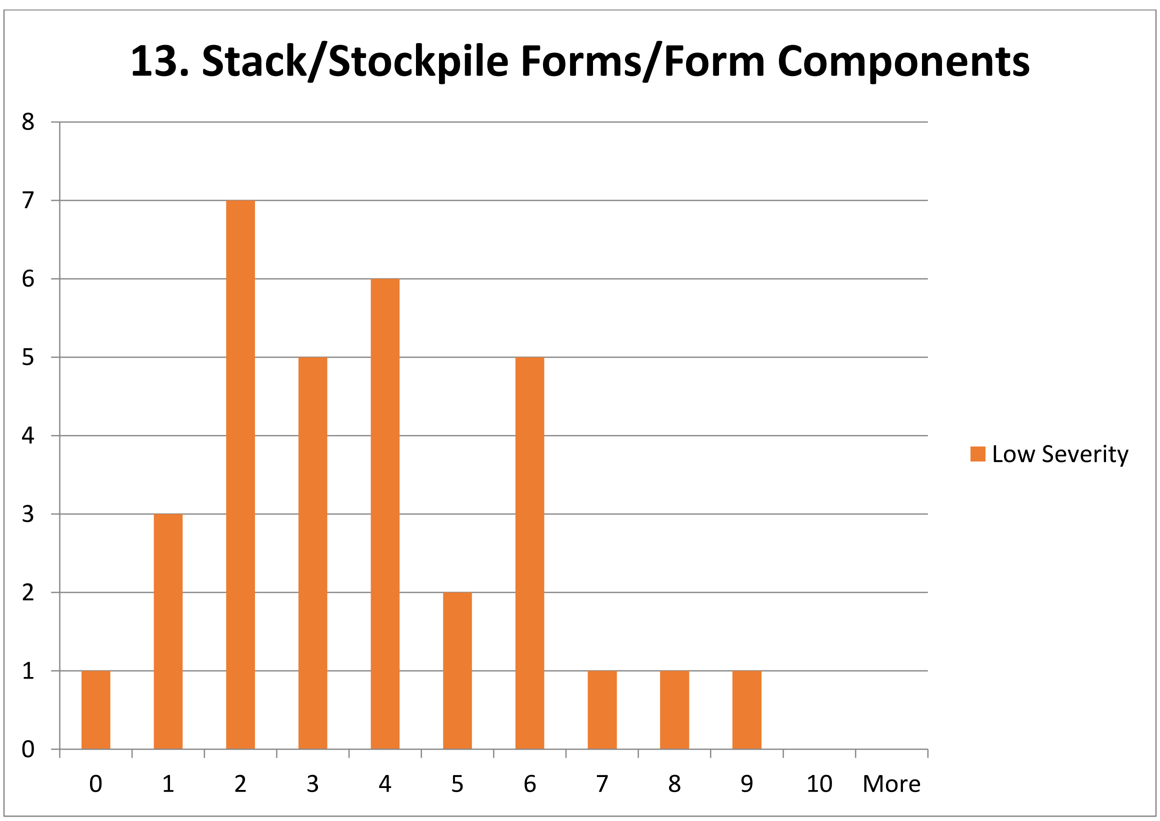
More
Low Severity


13. Stack/Stockpile Forms/Form Components
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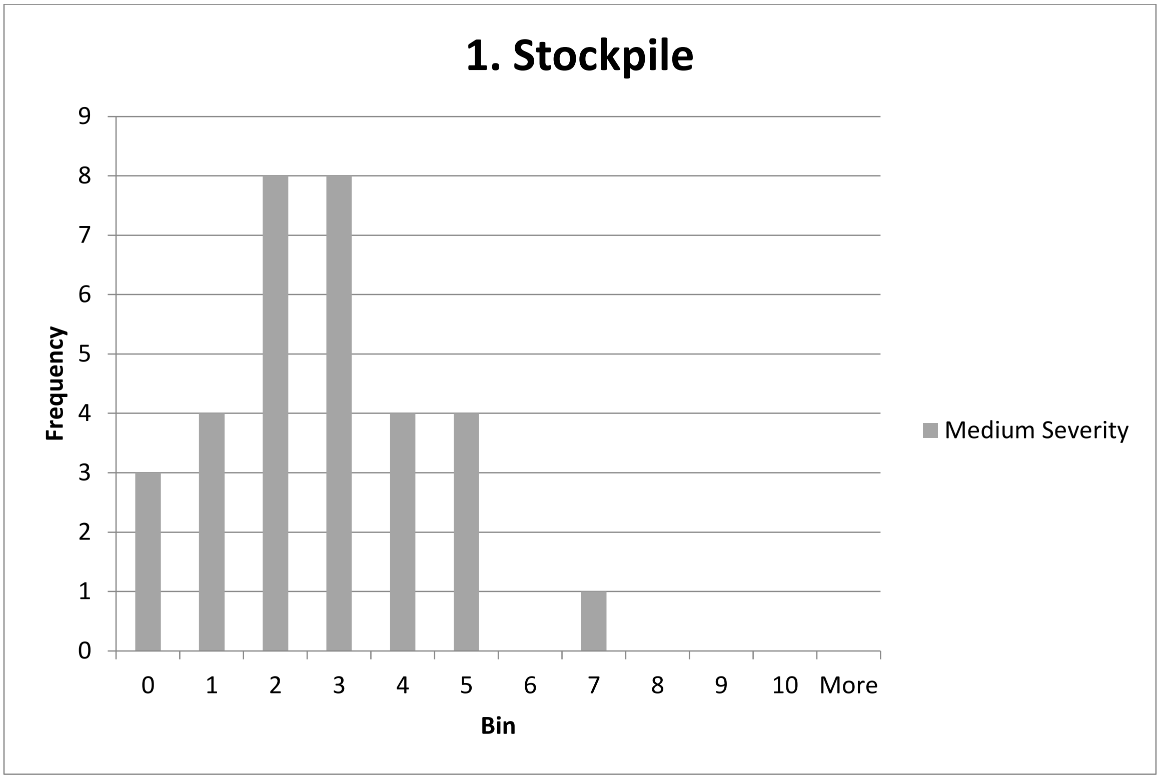
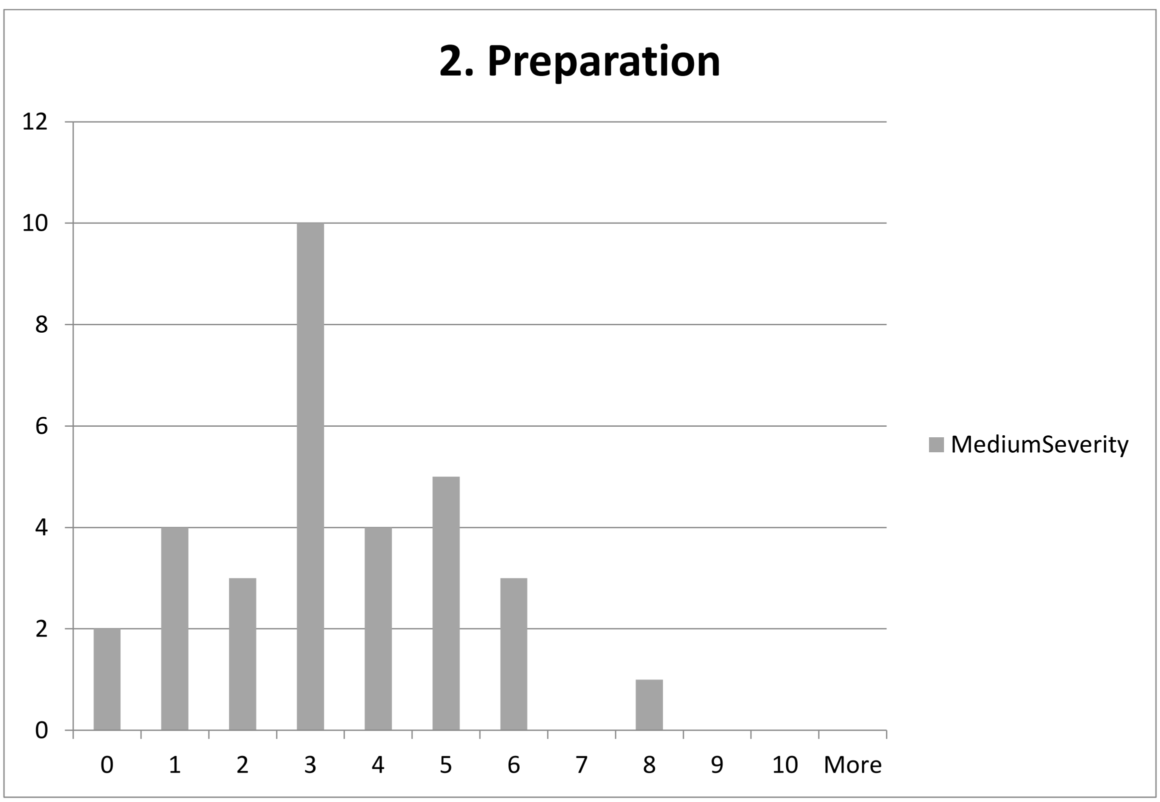
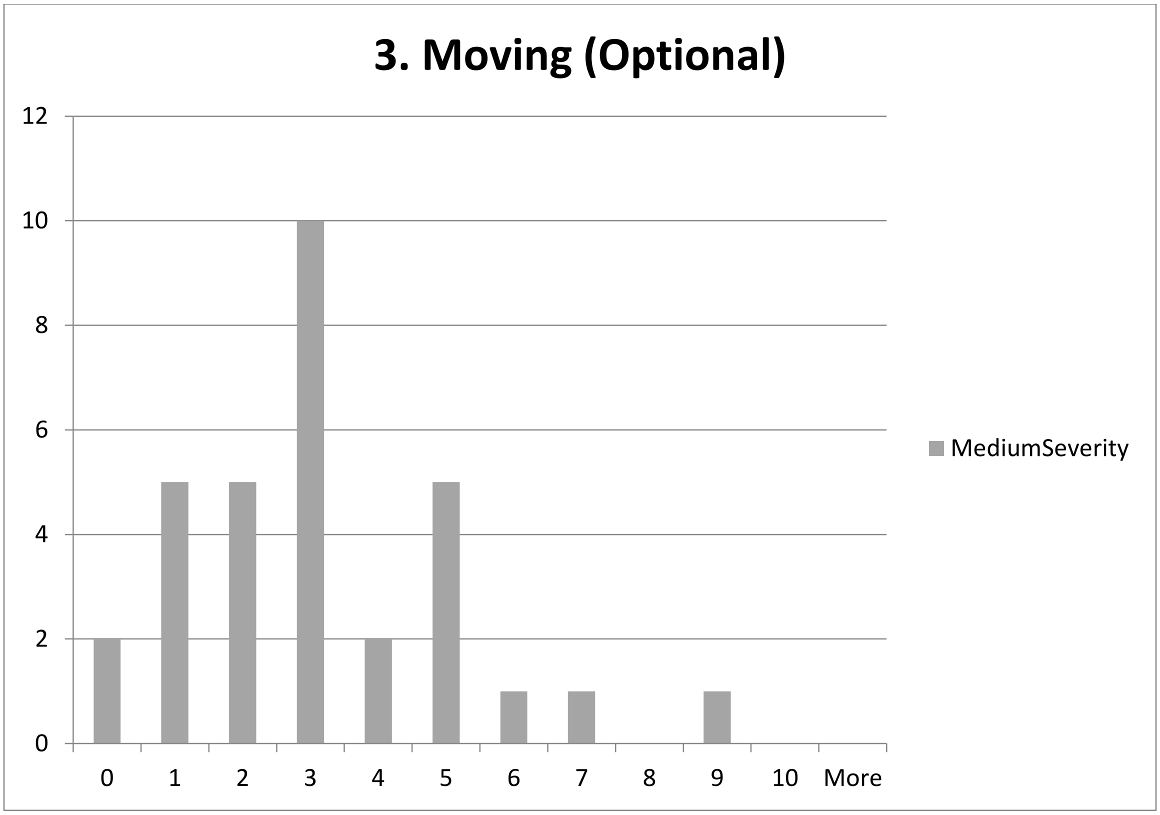
More
Low Severity

Histograms for Medium Severity:






3. Moving (Optional)
12
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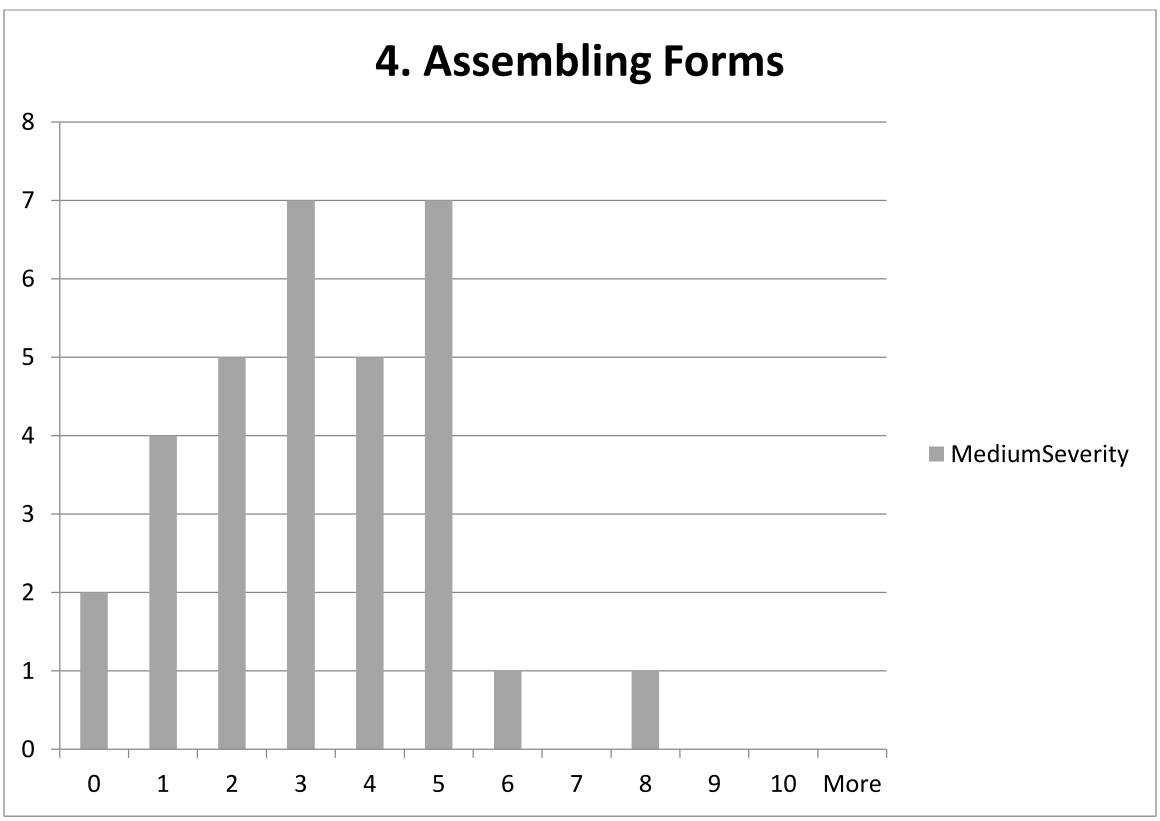
More
MediumSeverity


4. Assembling Forms
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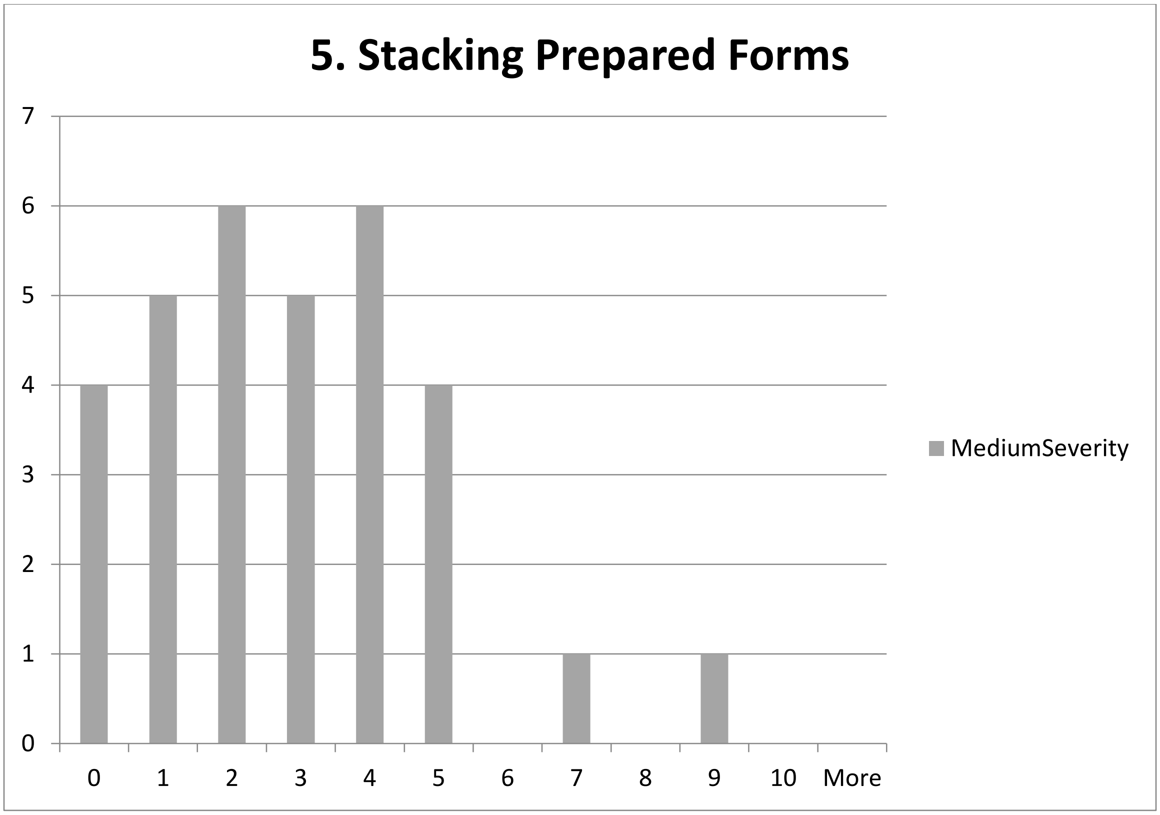
More
MediumSeverity


5. Stacking Prepared Forms
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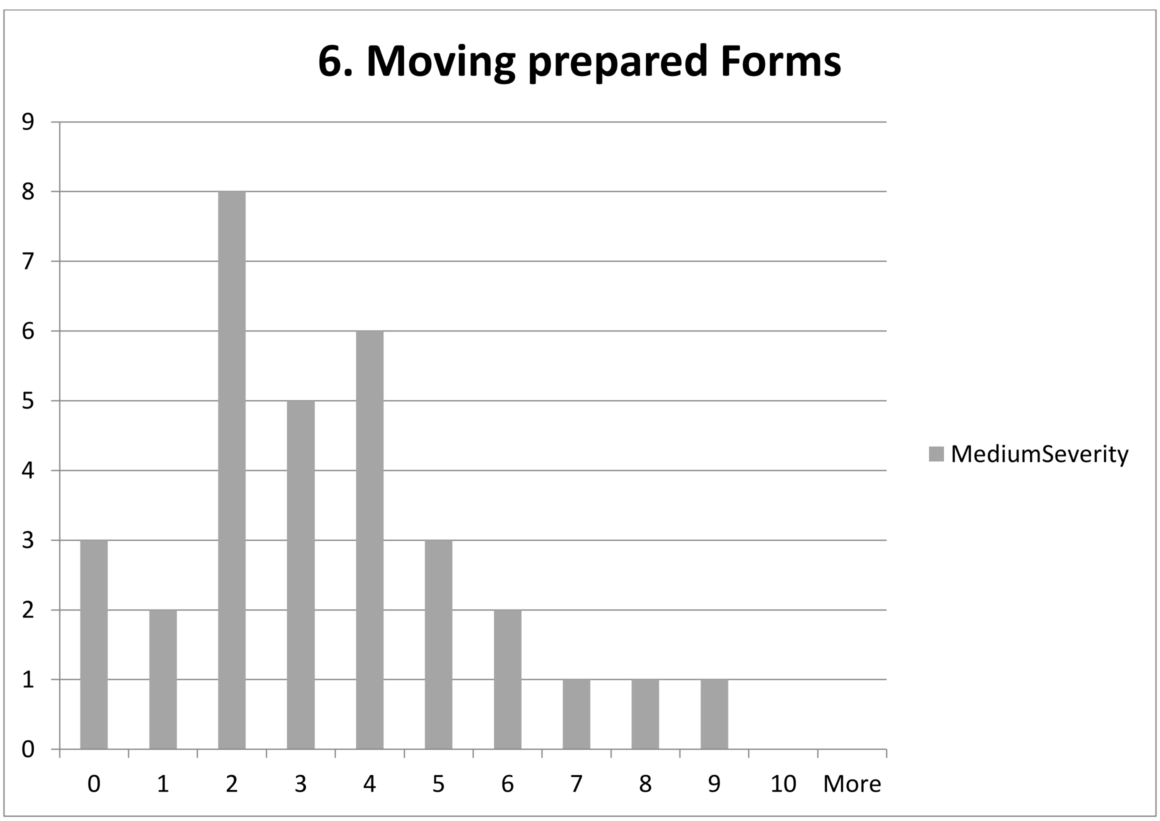
More
MediumSeverity


6. Moving prepared Forms
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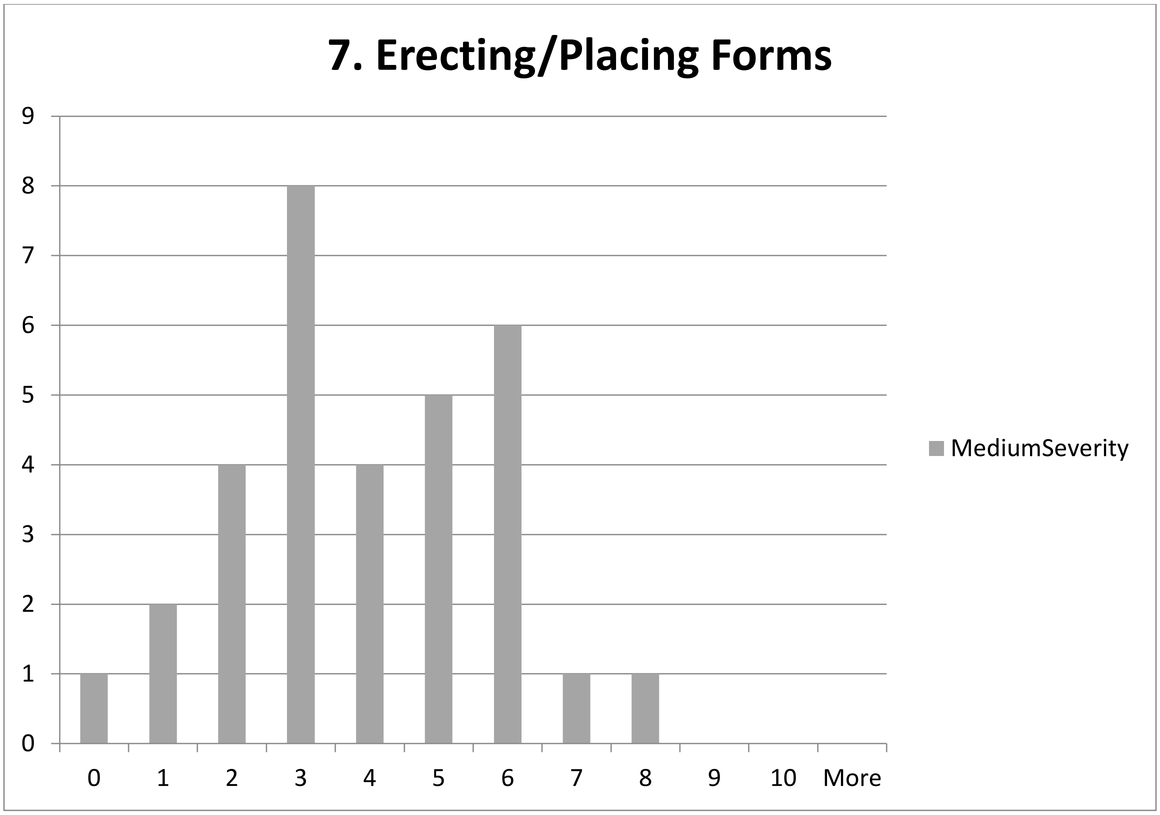
More
MediumSeverity


7. Erecting/Placing Forms
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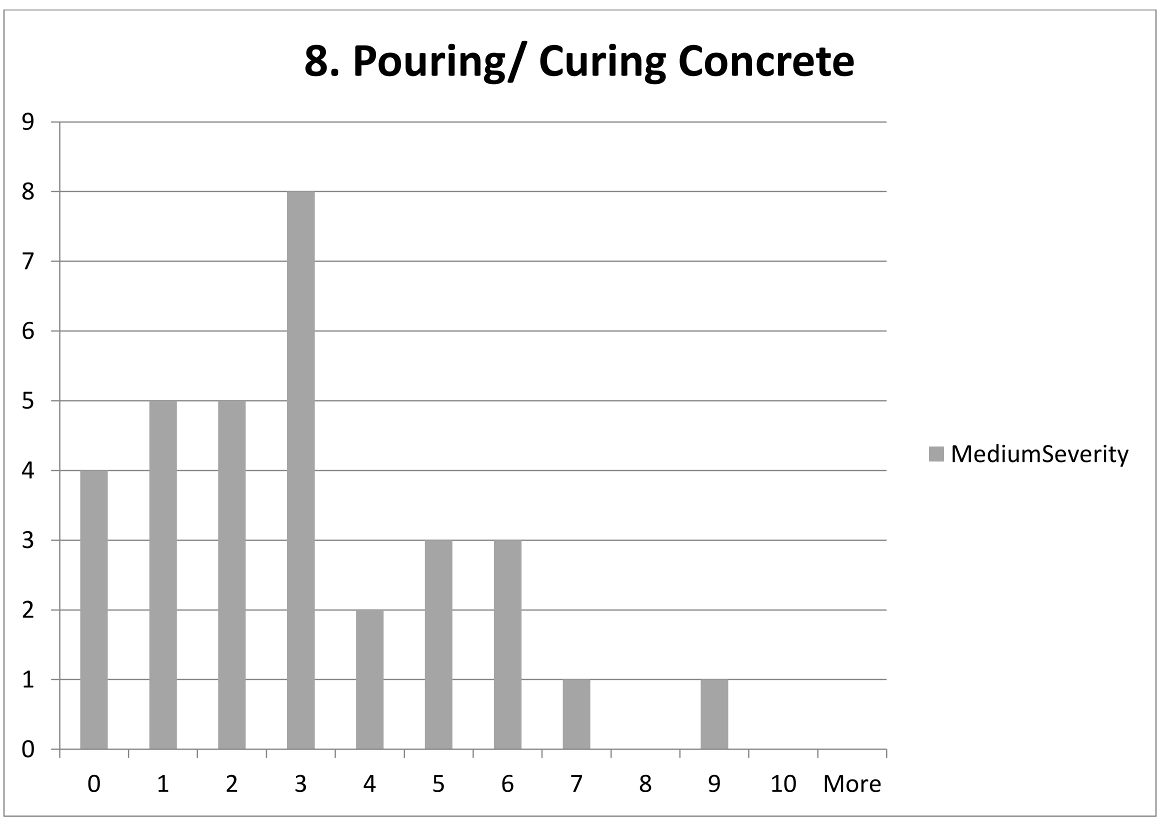
More
MediumSeverity


8. Pouring/ Curing Concrete
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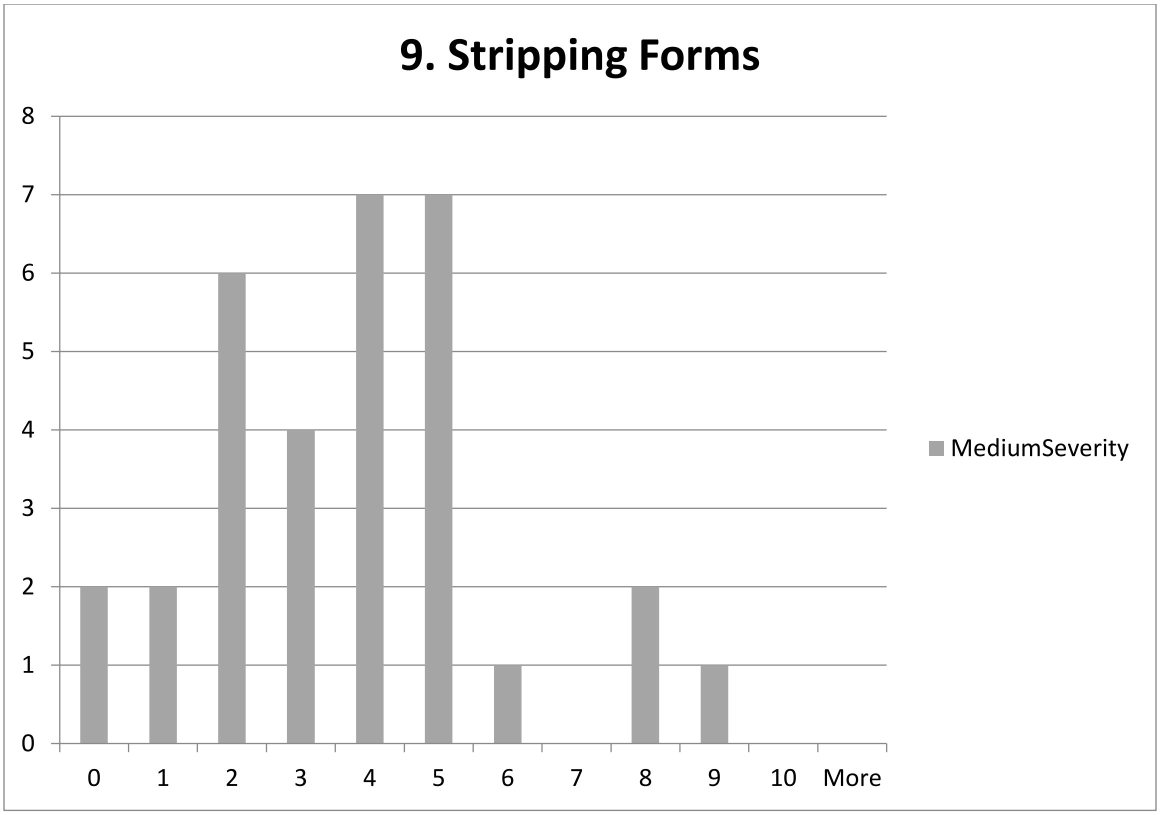
More
MediumSeverity


9. Stripping Forms
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7
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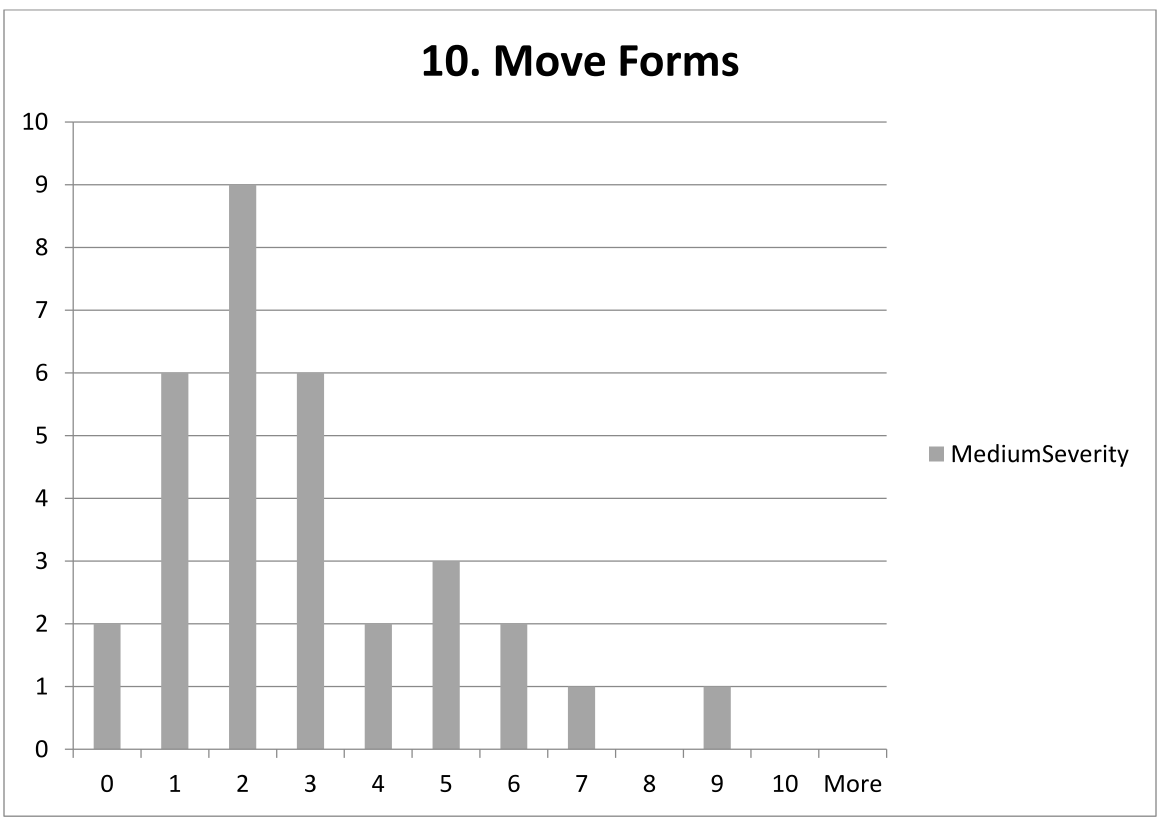
0 1 2 3 4 5 6 7 8 9 10 More
MediumSeverity


10. Move Forms
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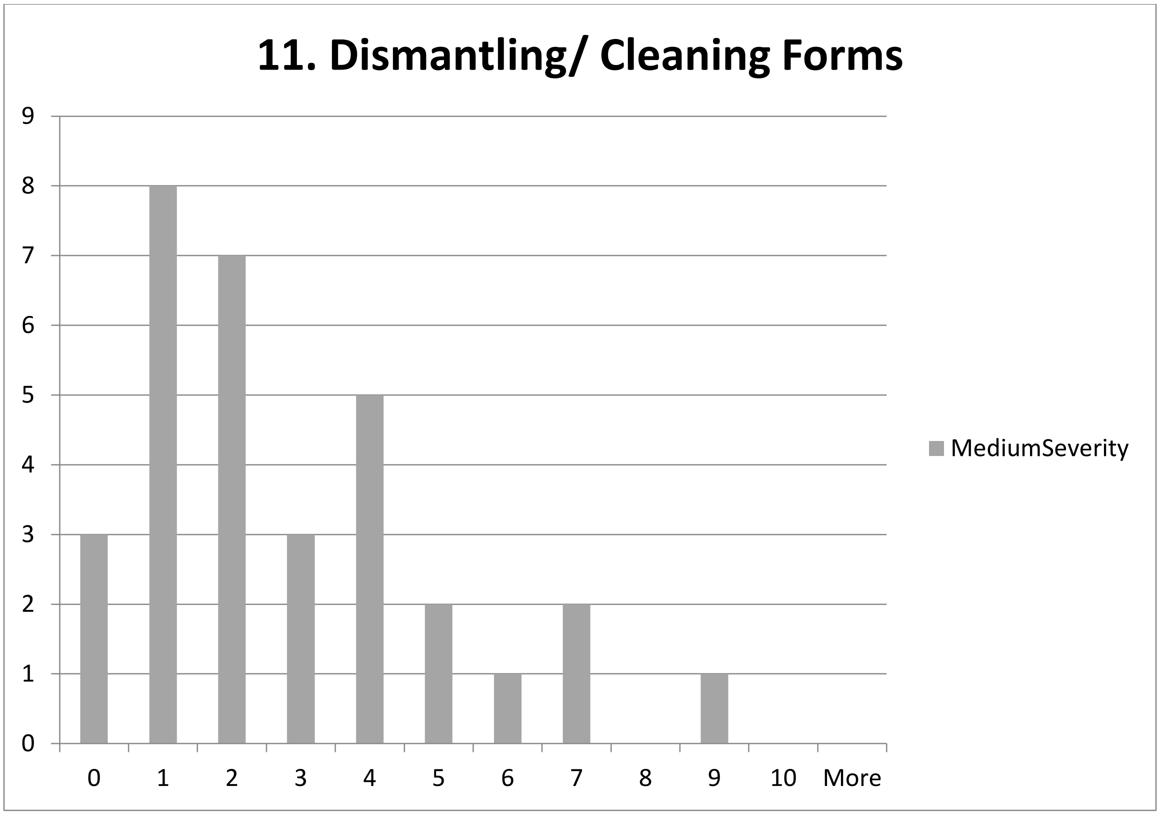
0 1 2 3 4 5 6 7 8 9 10 More
MediumSeverity


11. Dismantling/ Cleaning Forms
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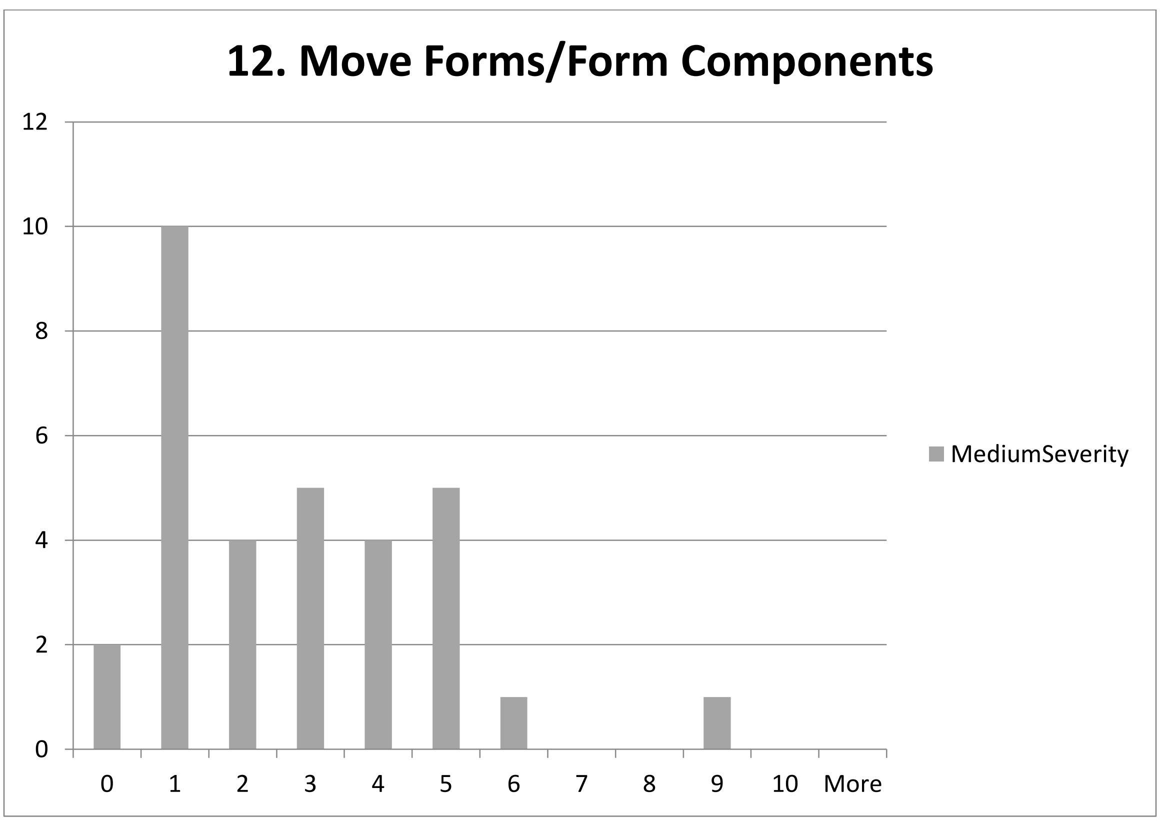
0 1 2 3 4 5 6 7 8 9 10 More
MediumSeverity


12. Move Forms/Form Components
12
10
8
6
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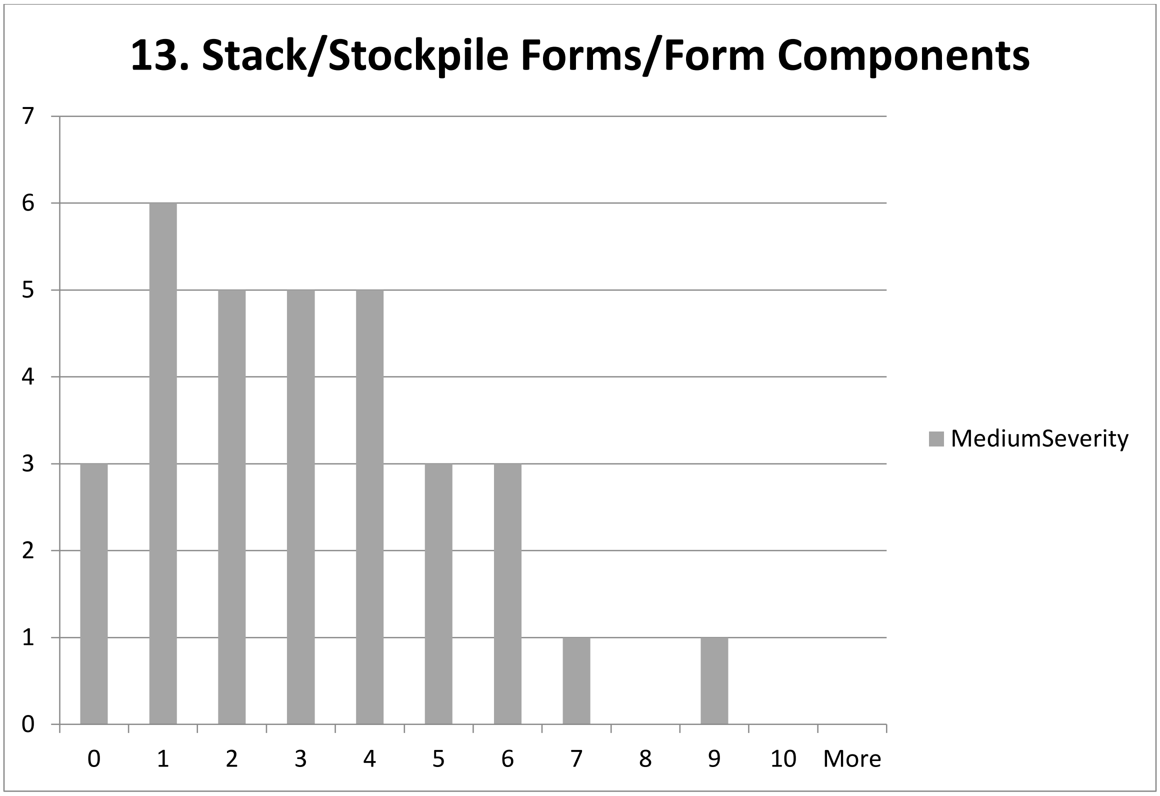
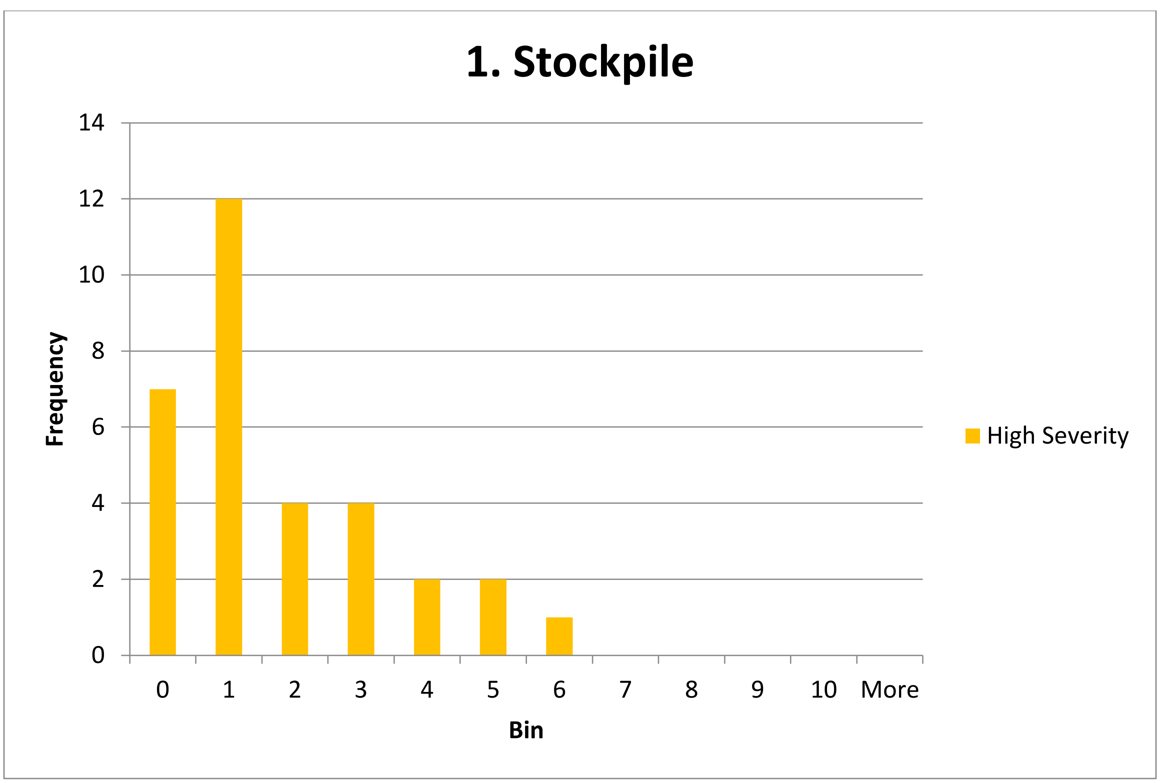
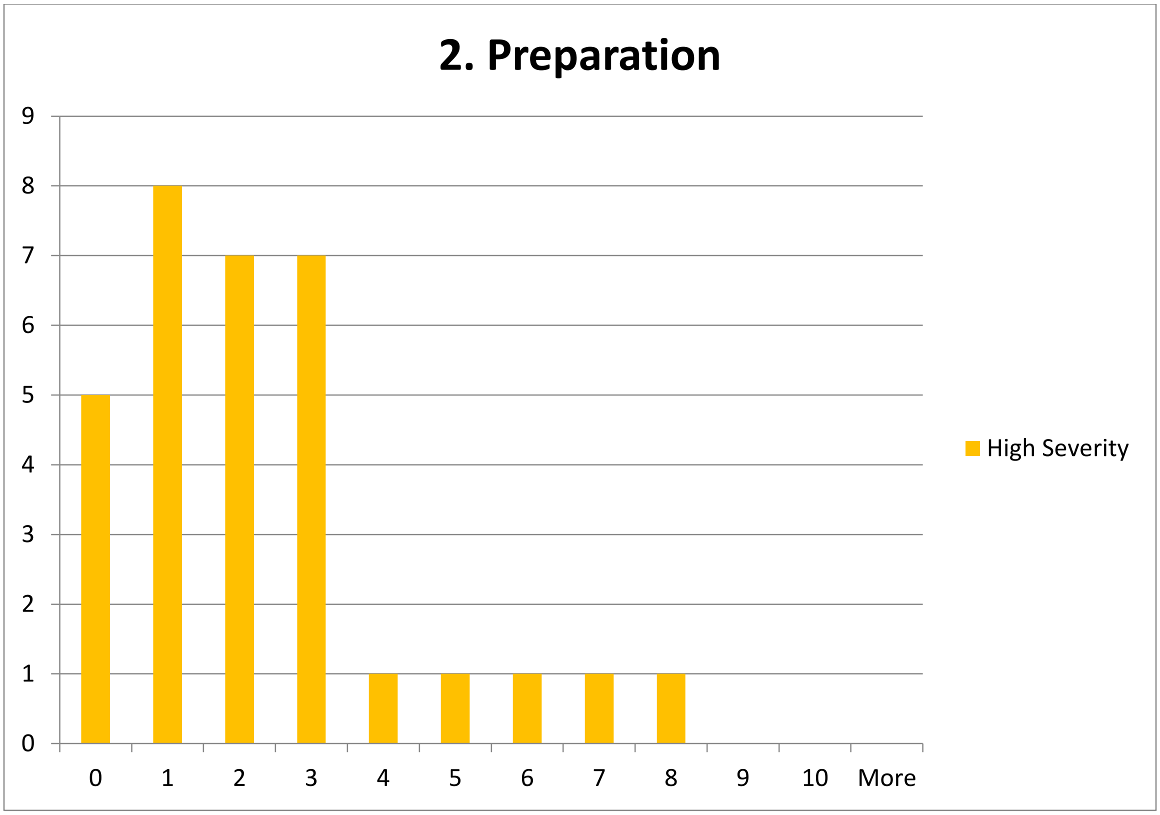
0 1 2 3 4 5 6 7 8 9 10 More
MediumSeverity



Histograms for High Severity:




2. Preparation
9
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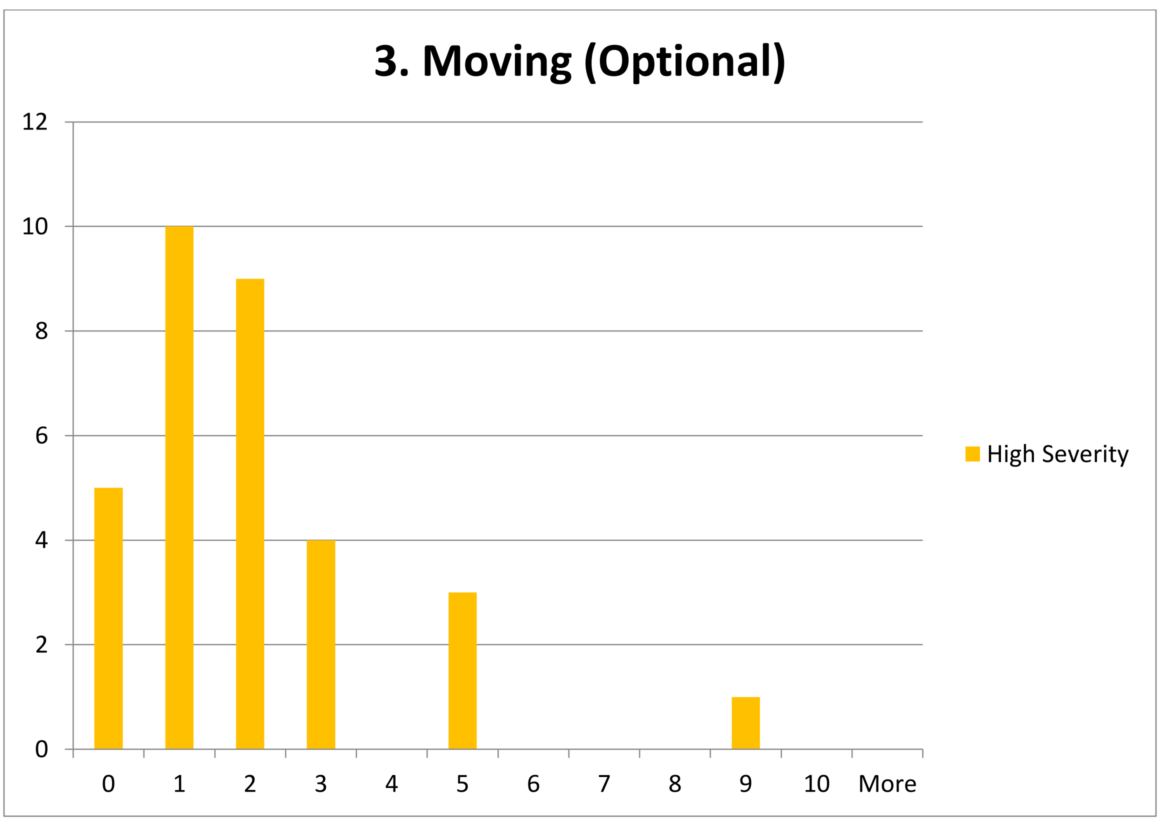
0 1 2 3 4 5 6 7 8 9 10 More
High Severity


3. Moving (Optional)
12
10
8
6
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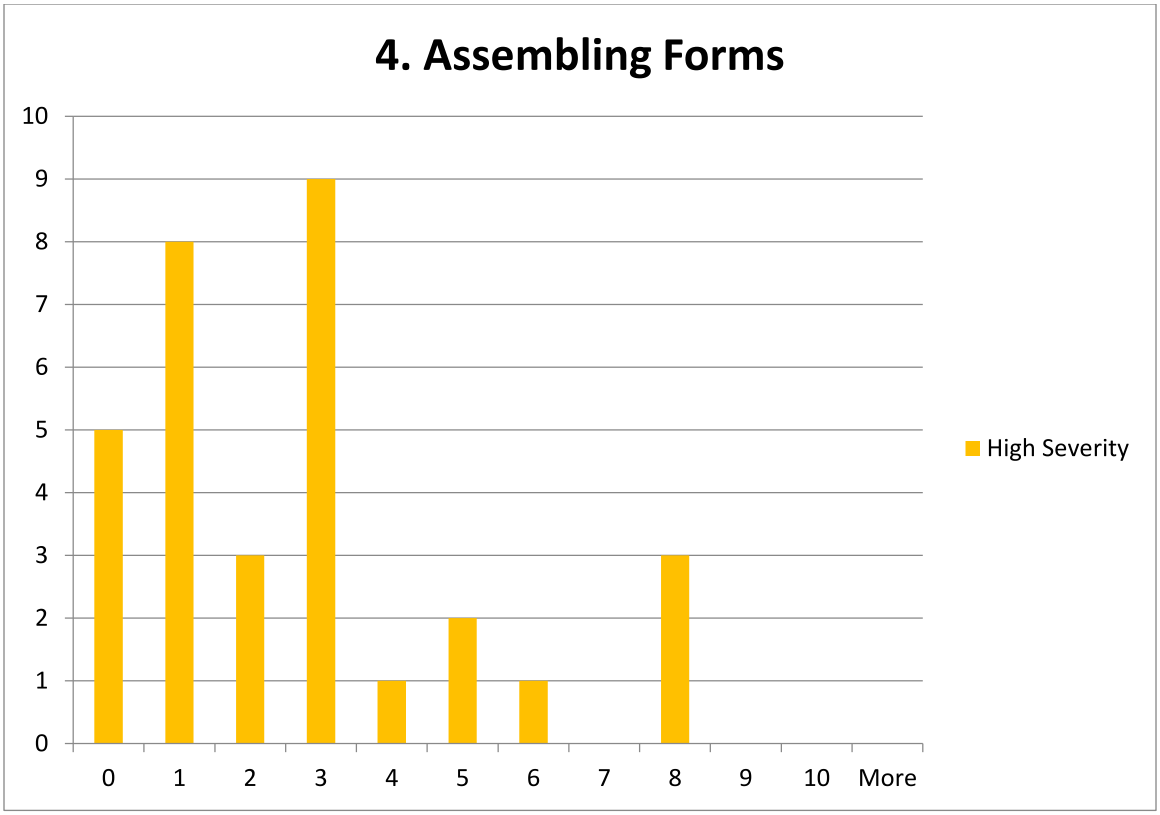
0 1 2 3 4 5 6 7 8 9 10 More
High Severity


4. Assembling Forms
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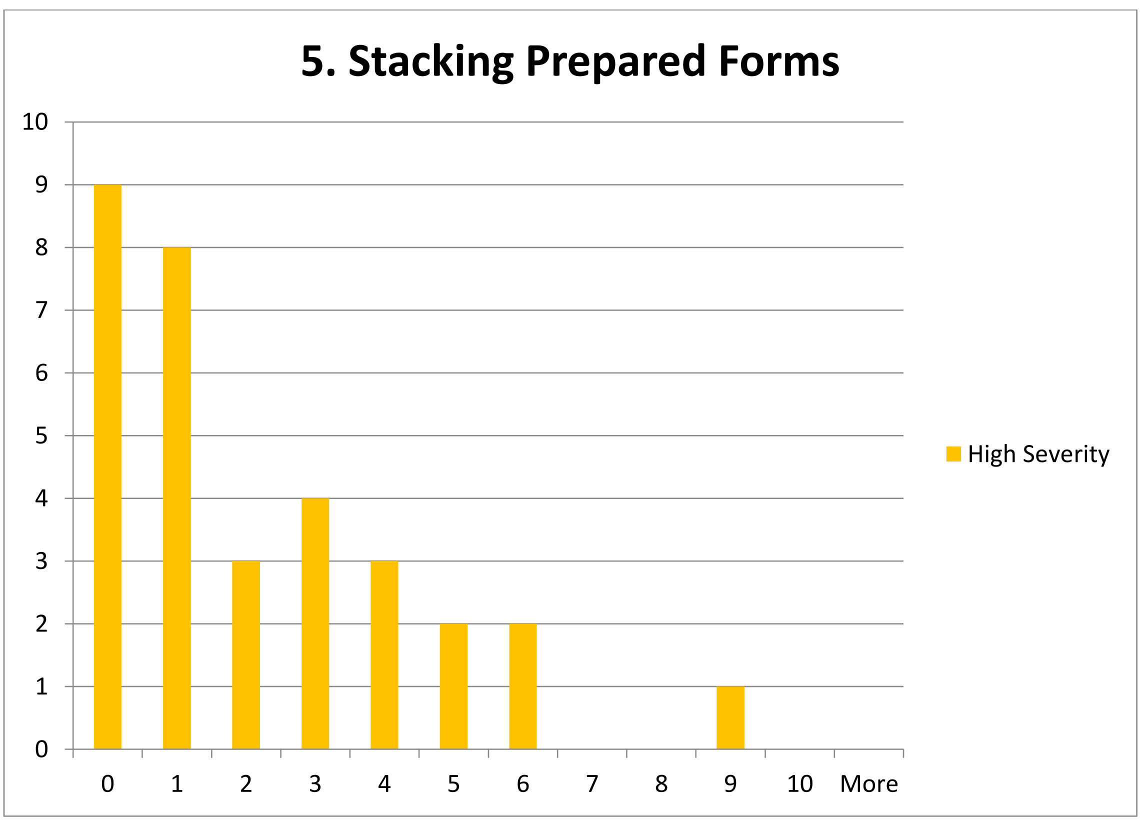
0 1 2 3 4 5 6 7 8 9 10 More
High Severity


5. Stacking Prepared Forms
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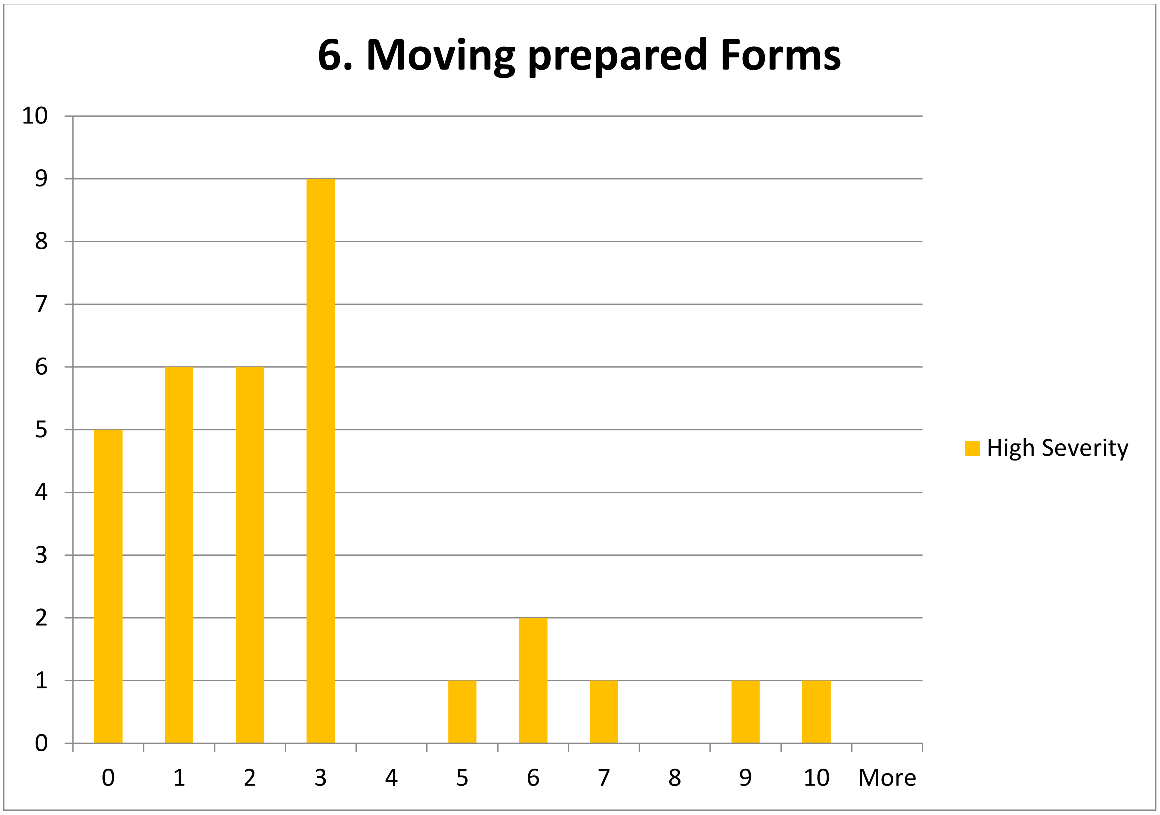
0 1 2 3 4 5 6 7 8 9 10 More
High Severity


6. Moving prepared Forms
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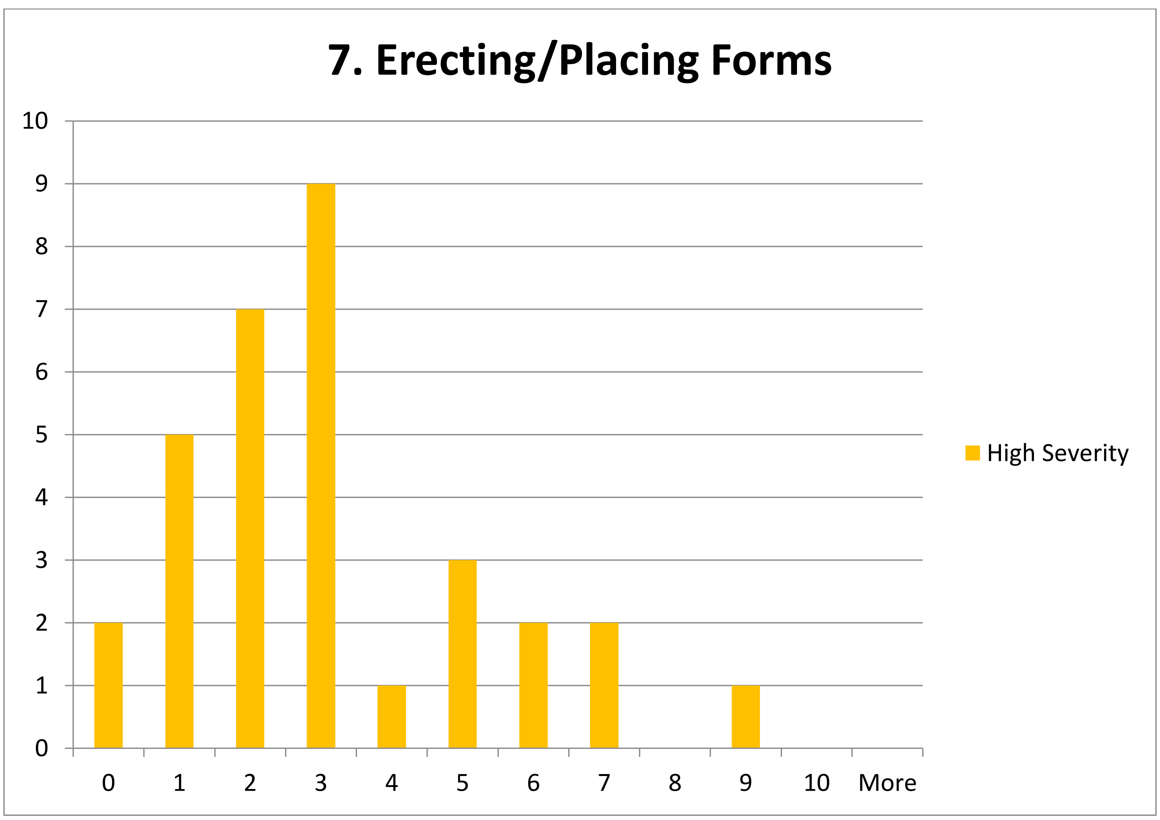
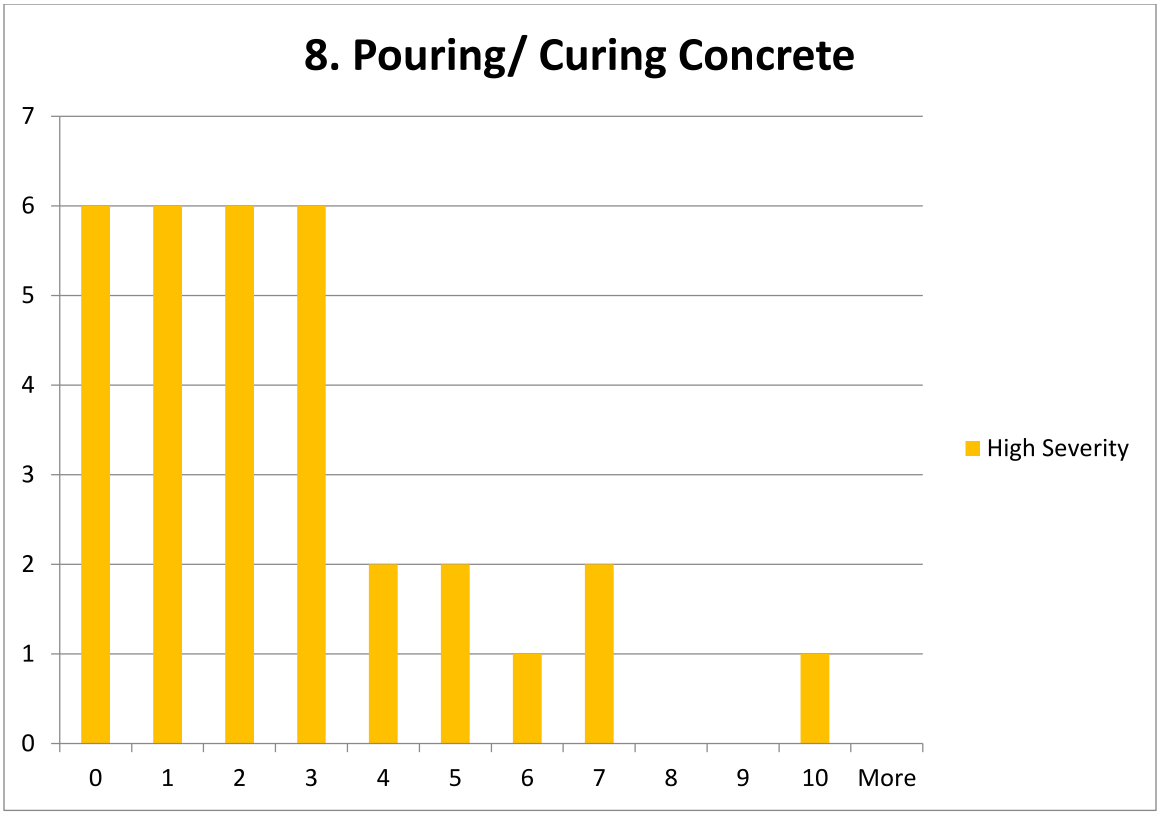
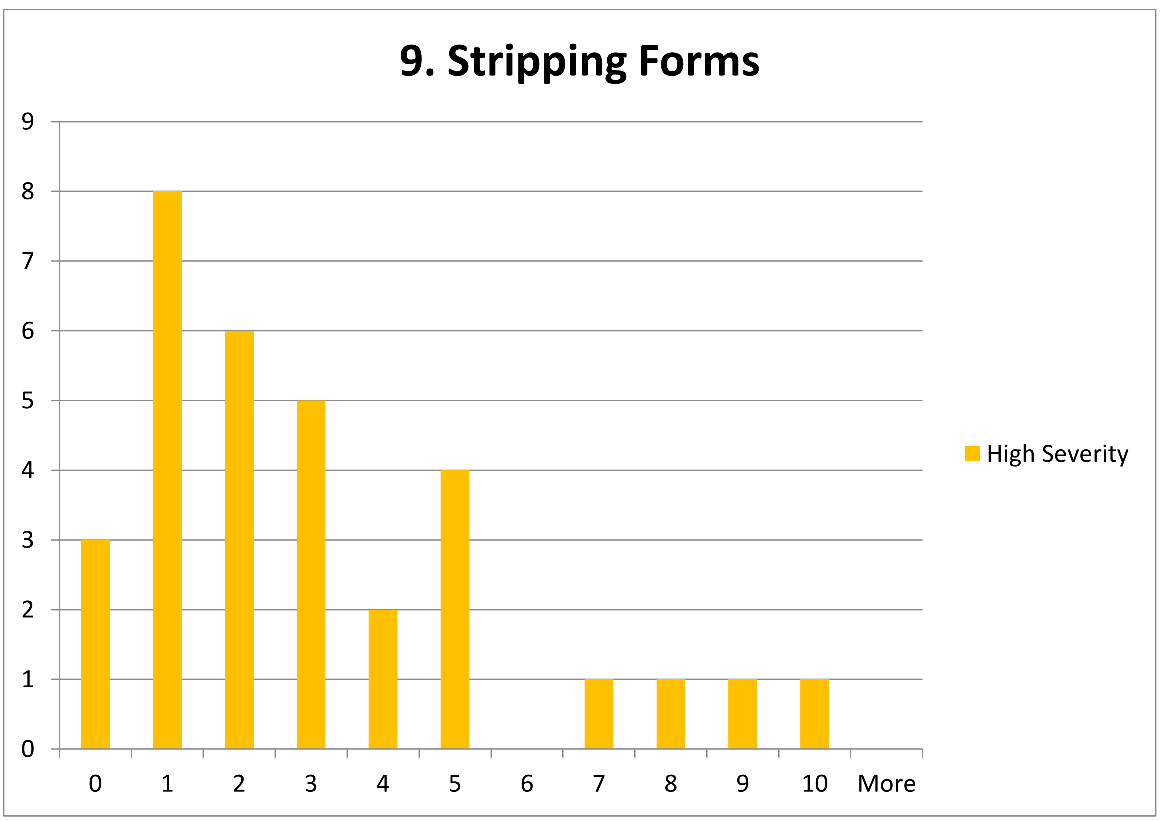
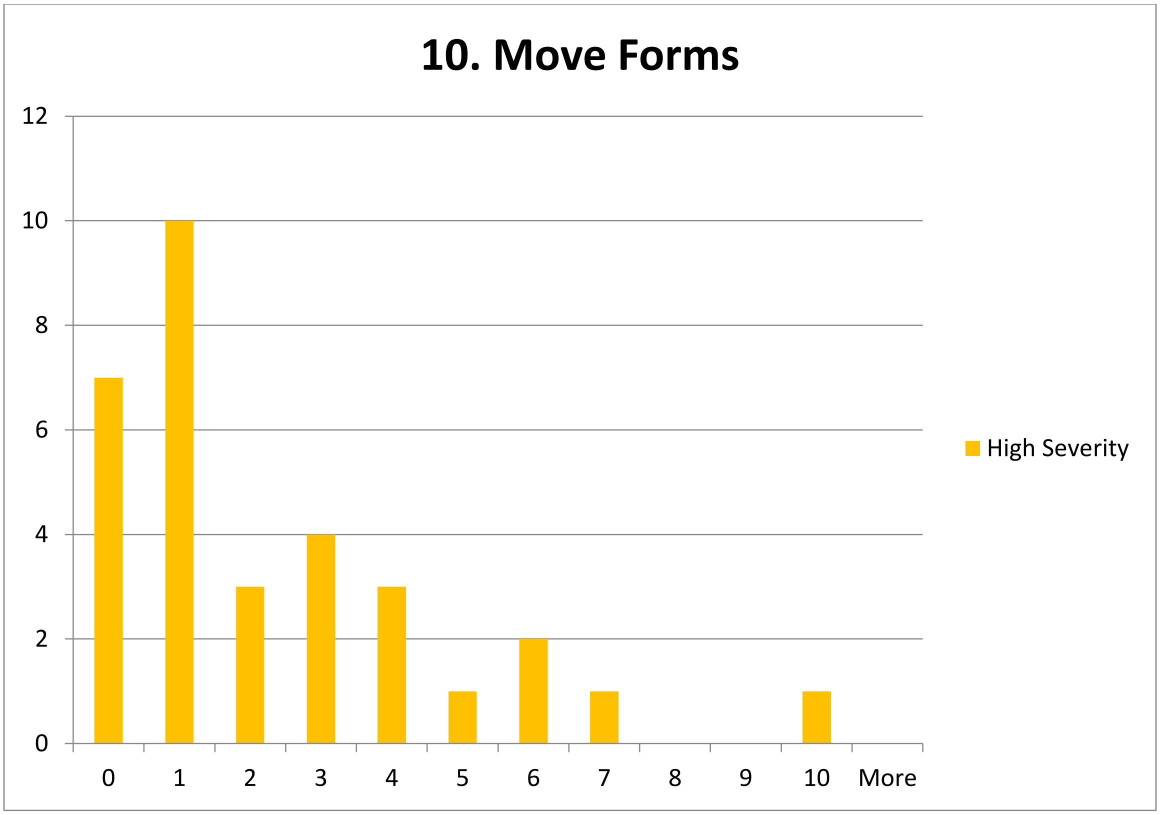
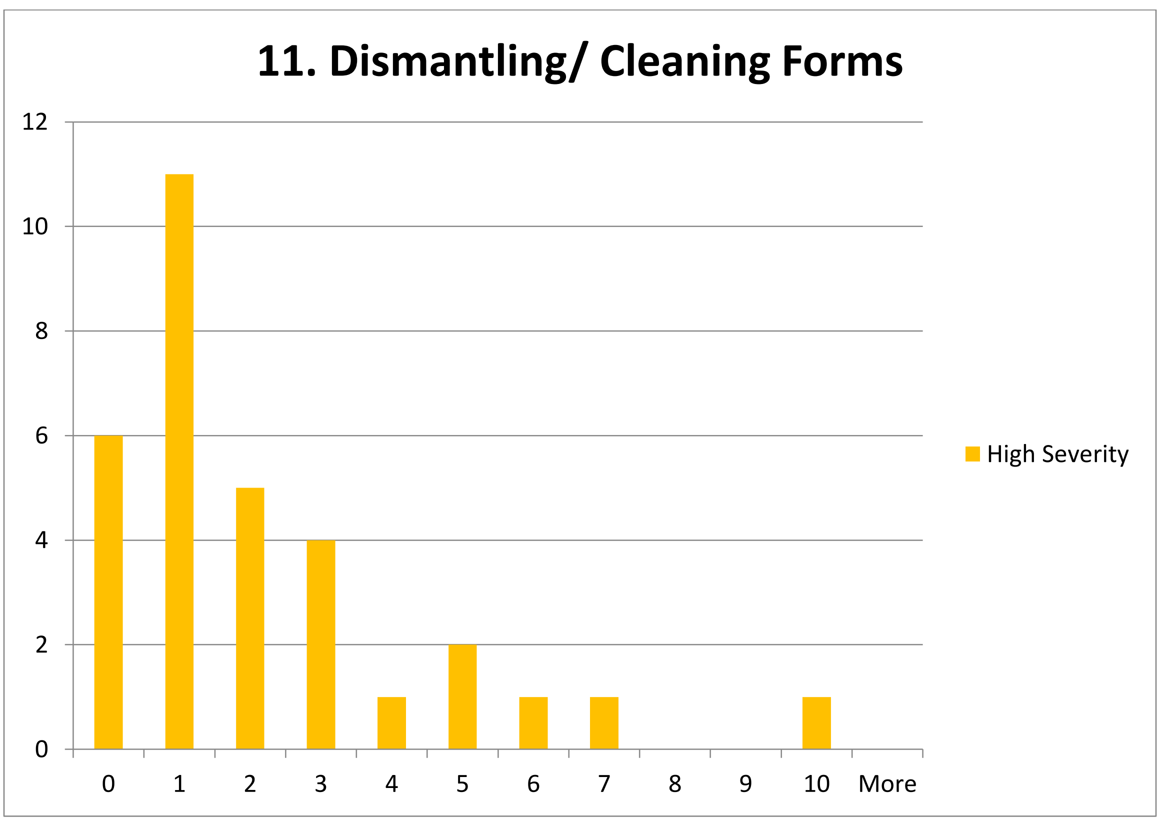
More
High Severity

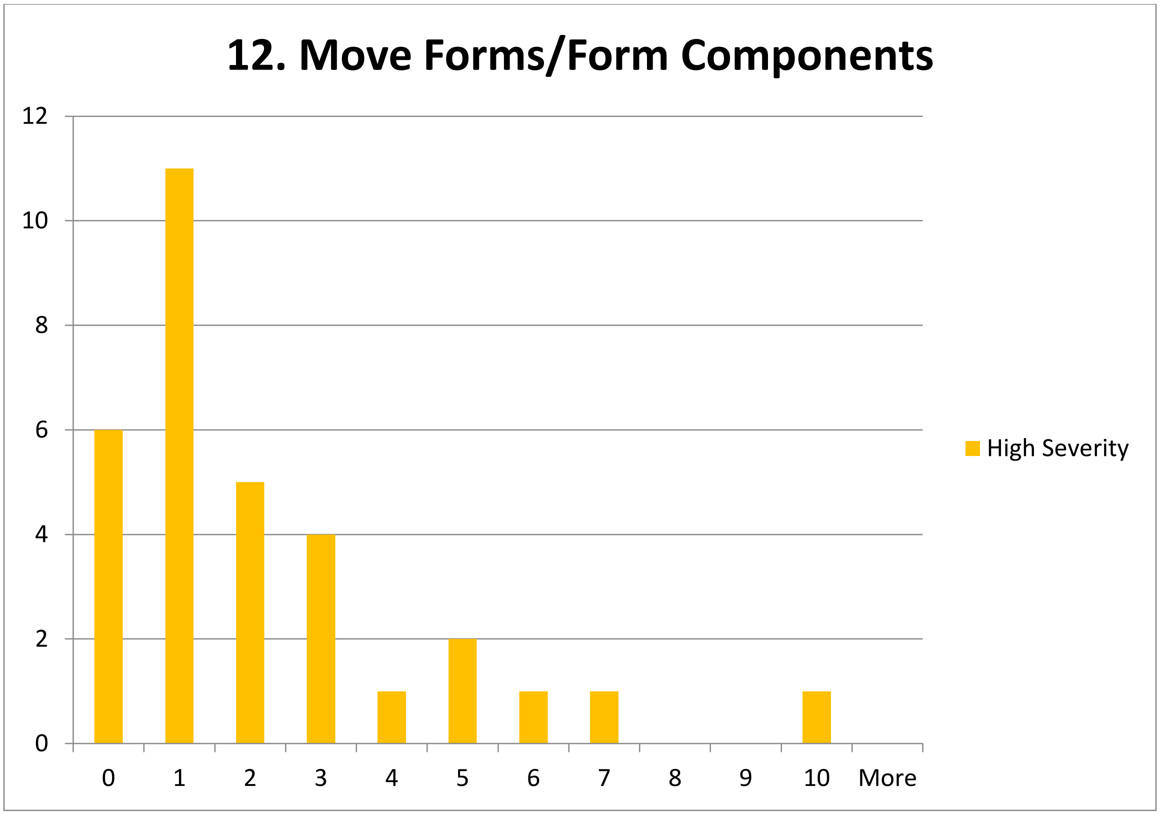

7. Erecting/Placing Forms
10
9
8
7
6
5
4
3
2
1
0
0
1
2
3
4
5
6
7
8
9
10
More
High Severity

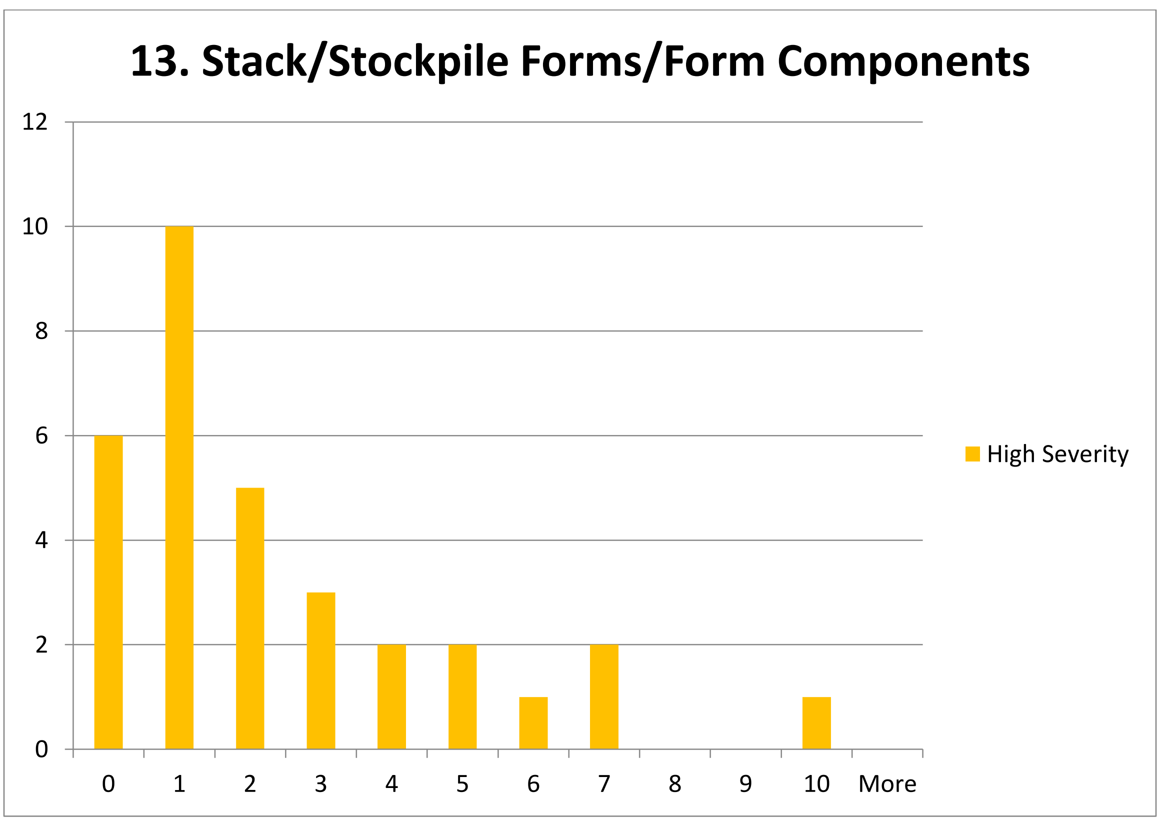

8. Pouring/ Curing Concrete
7
6
5
4
3
2
1
0
0 1 2 3 4 5 6 7 8 9 10 More
High Severity


9. Stripping Forms
9
8
7
6
5
4
3
2
1
0
0 1 2 3 4 5 6 7 8 9 10 More
High Severity

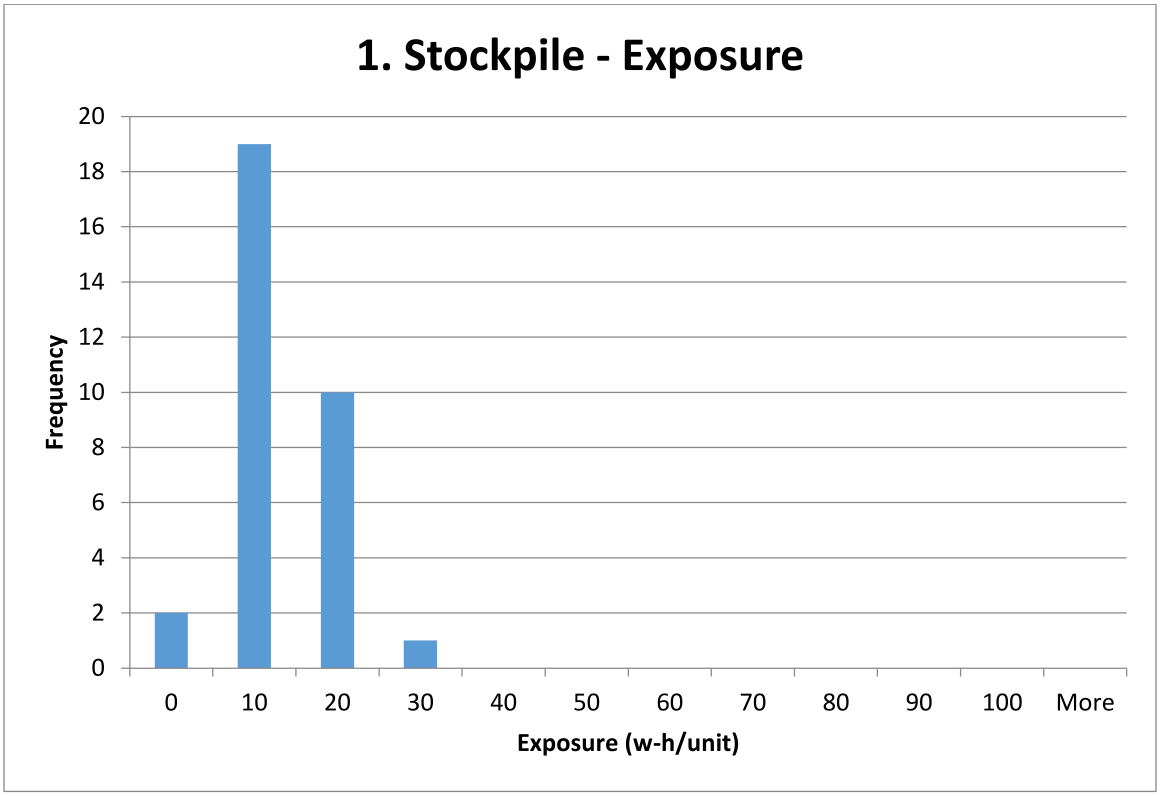

10. Move Forms
12
10
8
6
4
2
0
0
1
2
3
4
5
6
7
8
9
10
More
High Severity

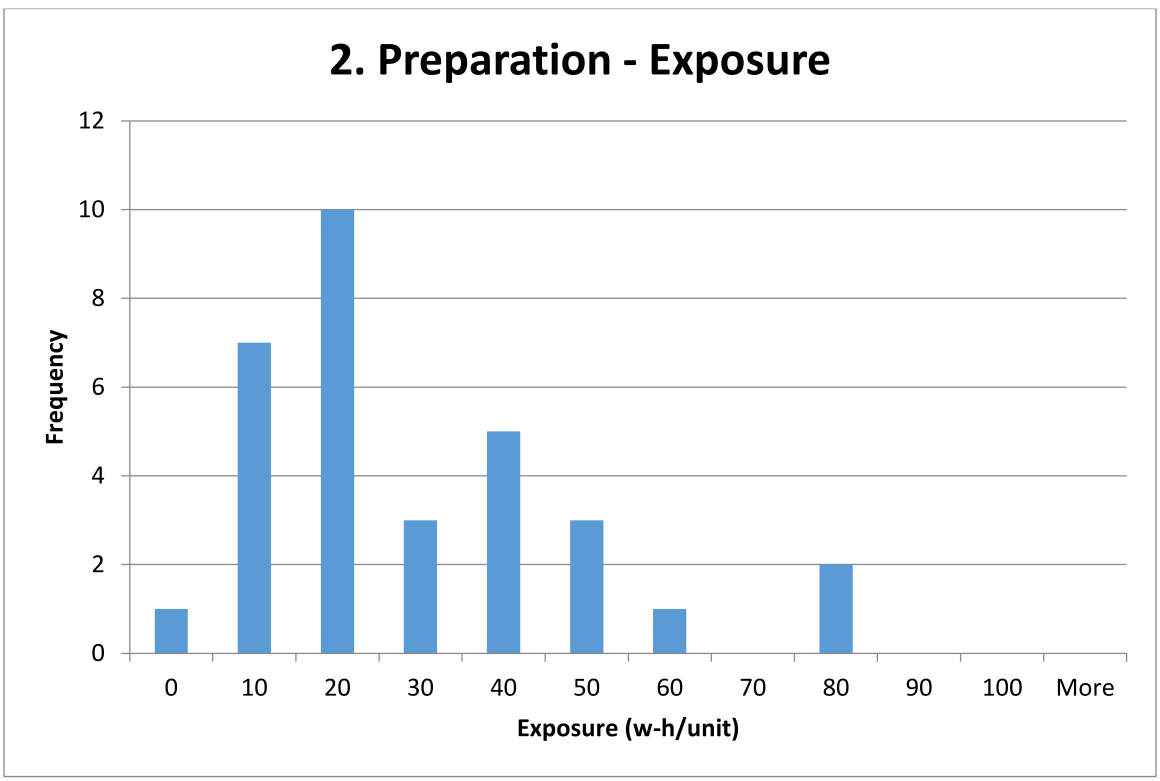

11. Dismantling/ Cleaning Forms
12
10
8
6
4
2
0
0
1
2
3
4
5
6
7
8
9
10
More
High Severity

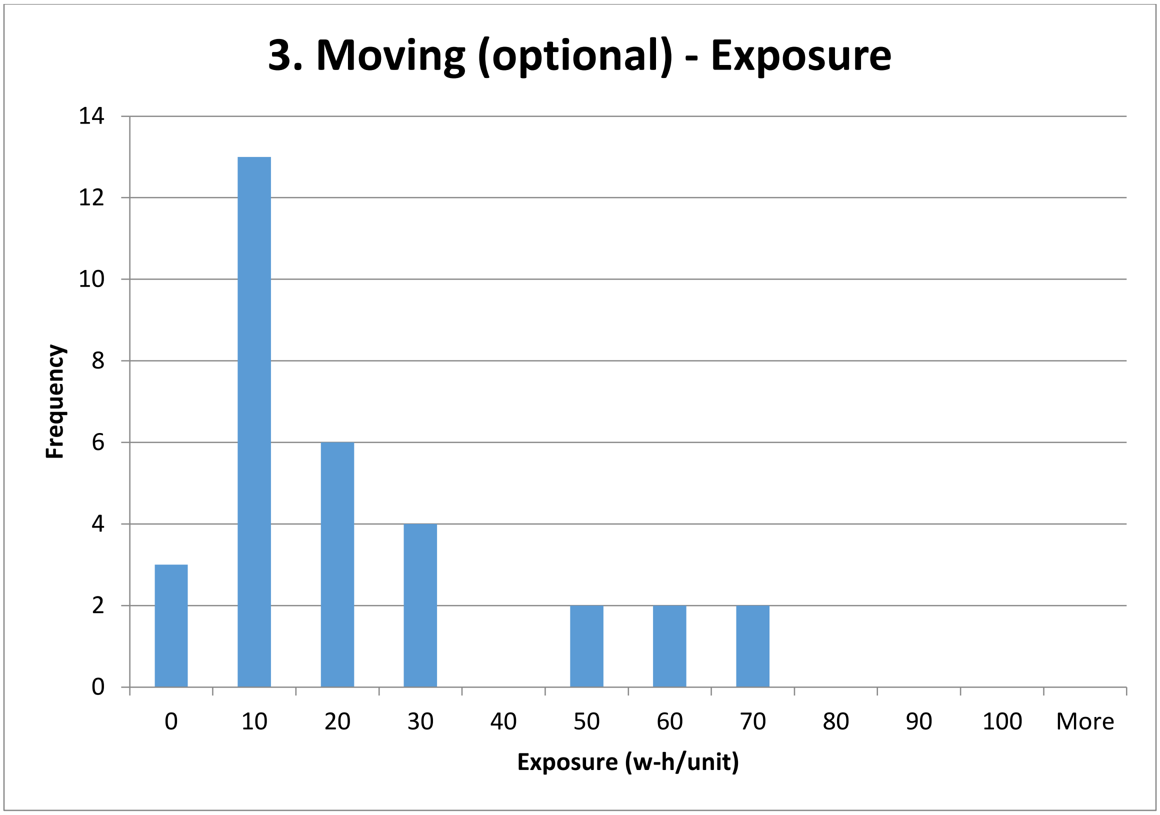

12. Move Forms/Form Components
12
10
8
6
4
2
0
0
1
2
3
4
5
6
7
8
9
10
More
High Severity

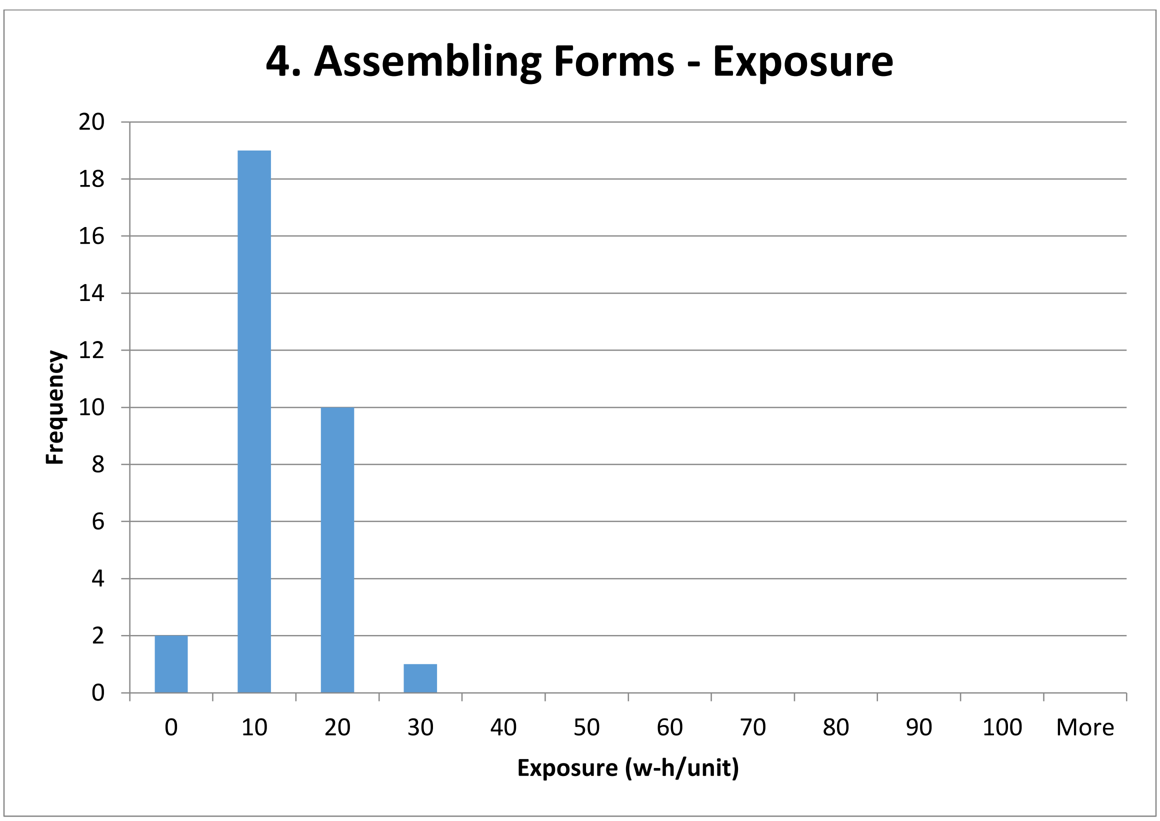

13. Stack/Stockpile Forms/Form Components
12
10
8
6
4
2
0
0
1
2
3
4
5
6
7
8
9
10
More
High Severity

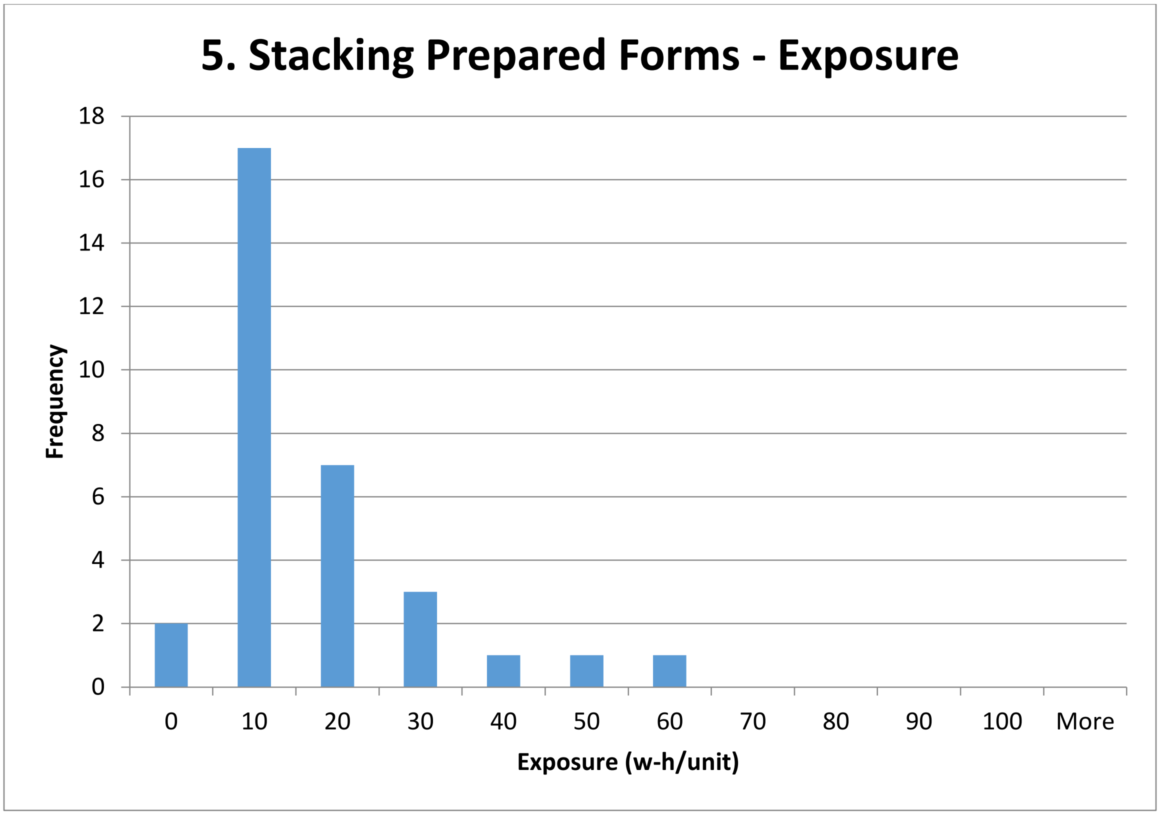
Histograms for Activity Exposure:

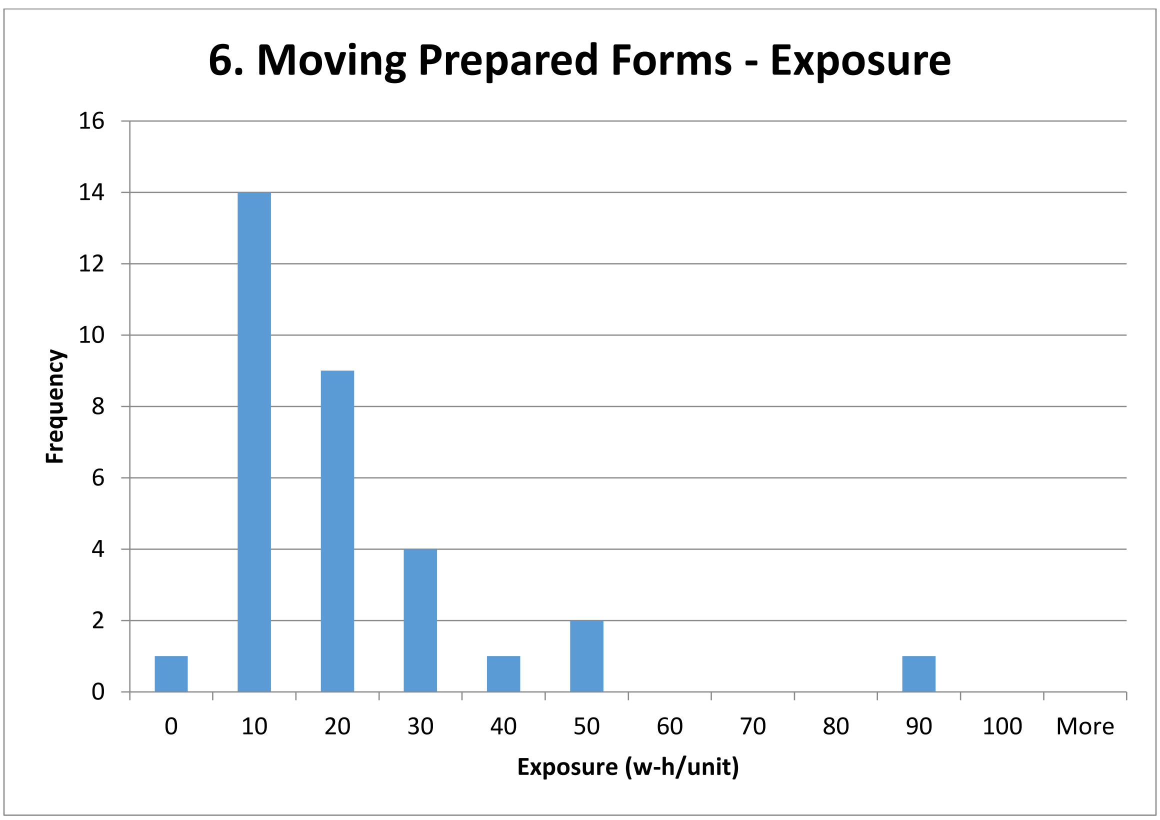


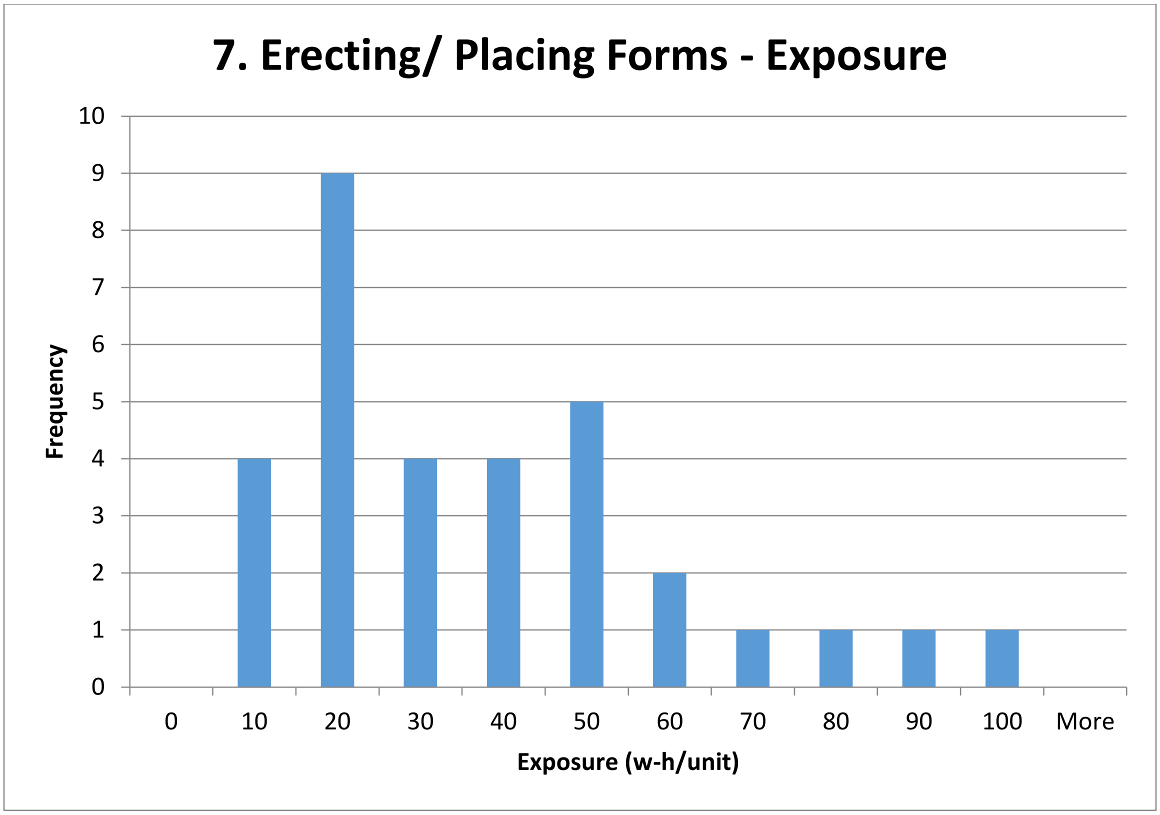


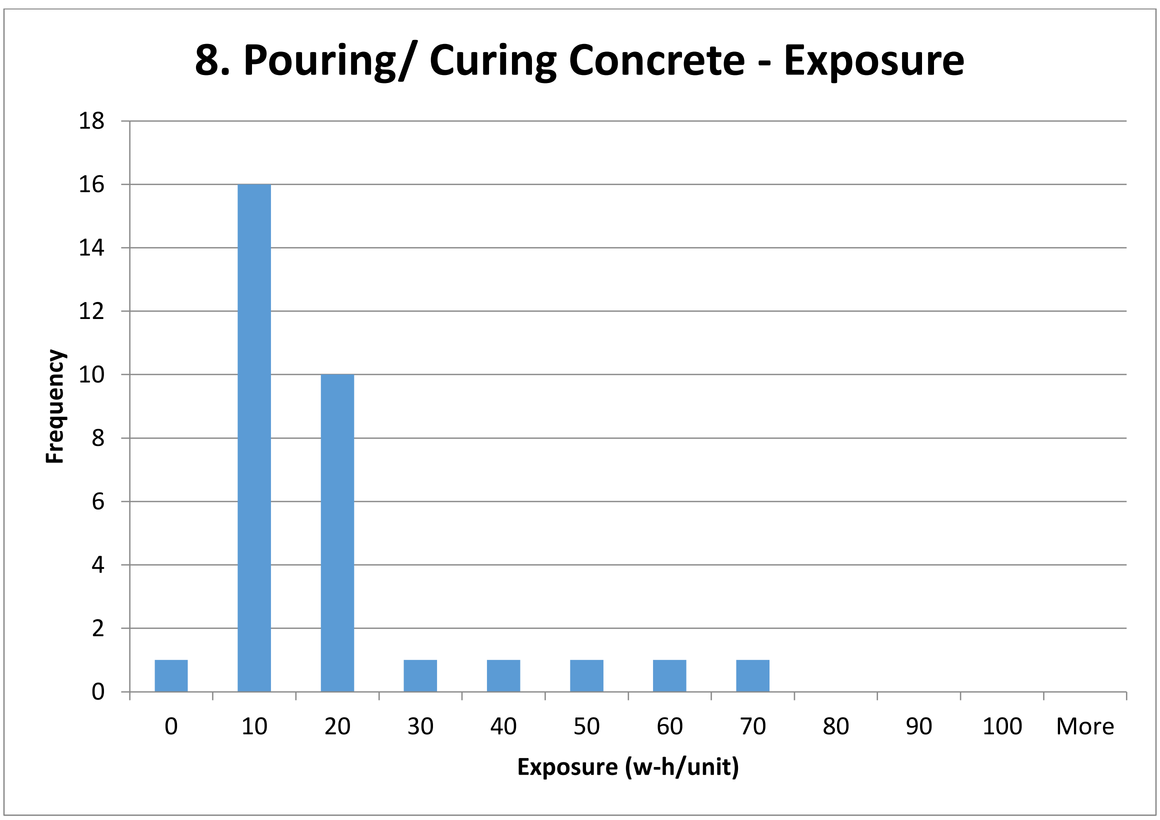

3. Moving (optional) - Exposure
Frequency
14
12
10
8
6
4
2
0
0
10
20
30
40
50
60
70
80
90
100
More
Exposure (w-h/unit)

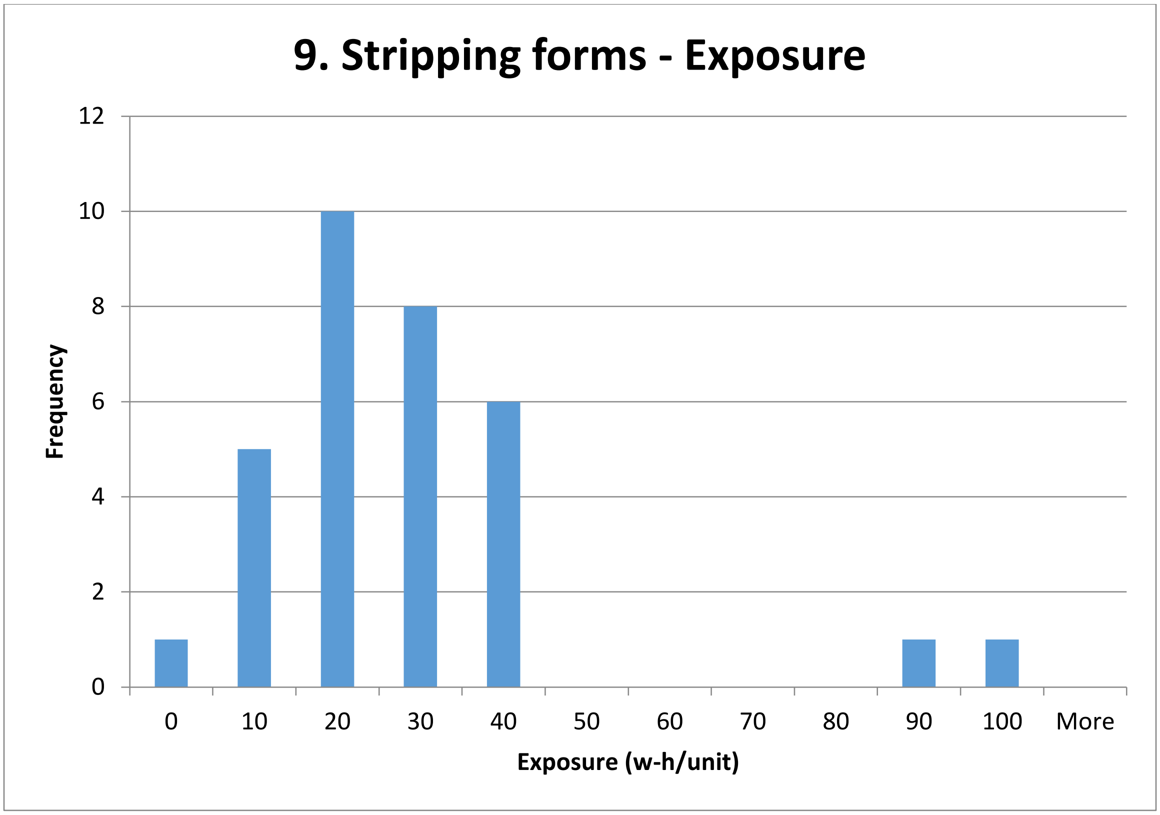

4. Assembling Forms - Exposure
Frequency
20
18
16
14
12
10
8
6
4
2
0
0
10
20
30
40
50
60
70
80
90
100
More
Exposure (w-h/unit)

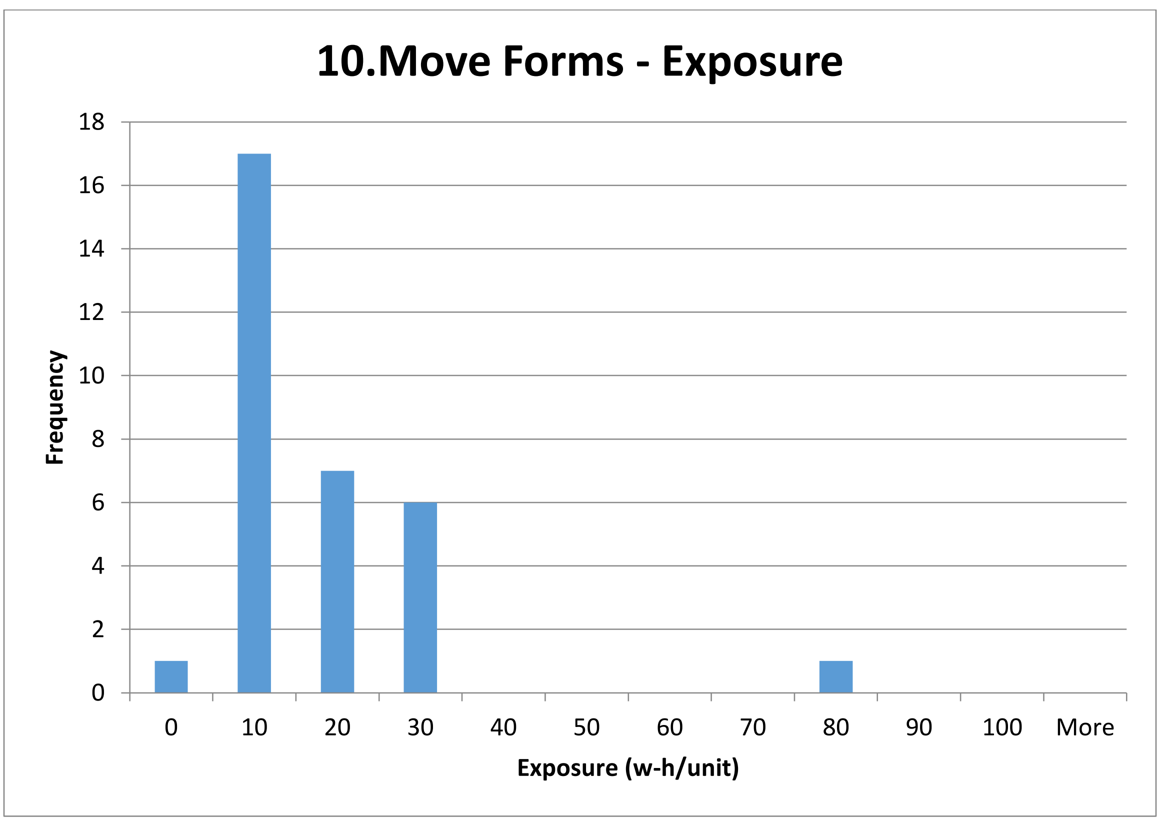

5. Stacking Prepared Forms - Exposure
Frequency
18
16
14
12
10
8
6
4
2
0
0
10
20
30
40
50
60
70
80
90
100
More
Exposure (w-h/unit)

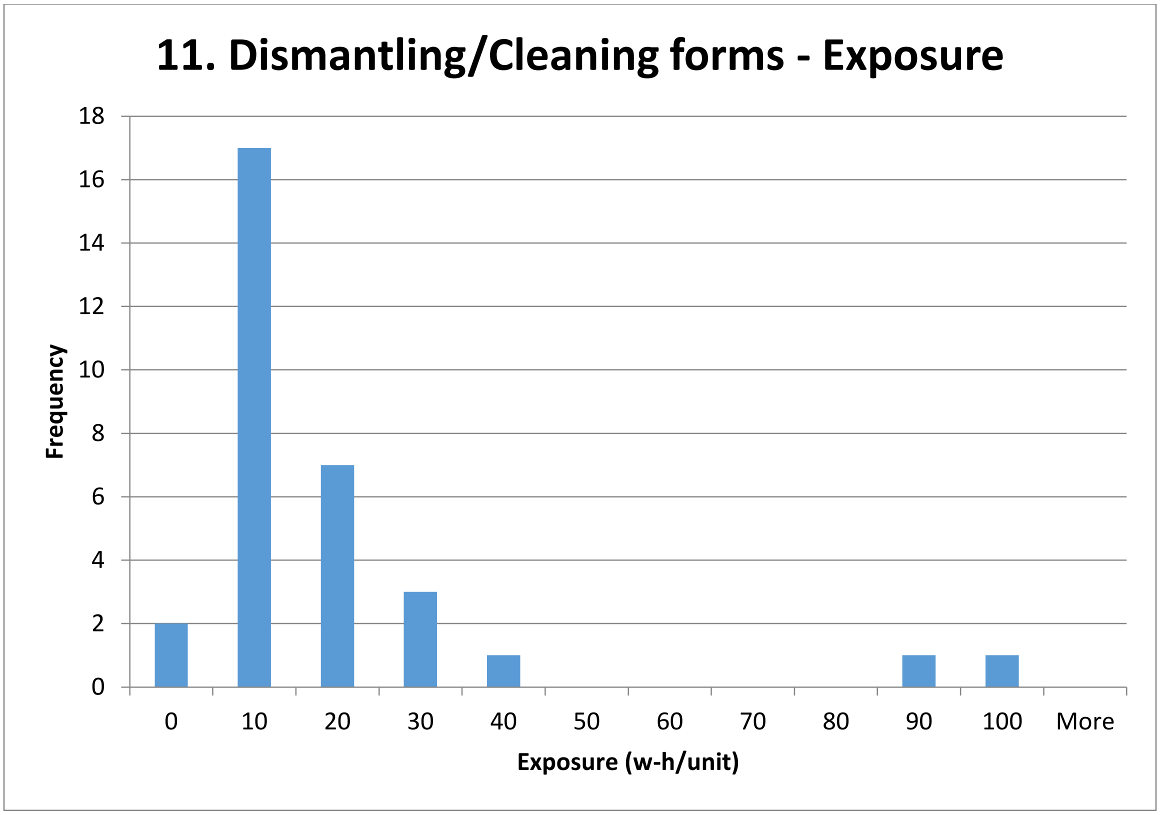

6. Moving Prepared Forms - Exposure
Frequency
16
14
12
10
8
6
4
2
0
0
10
20
30
40
50
60
70
80
90
100
More
Exposure (w-h/unit)

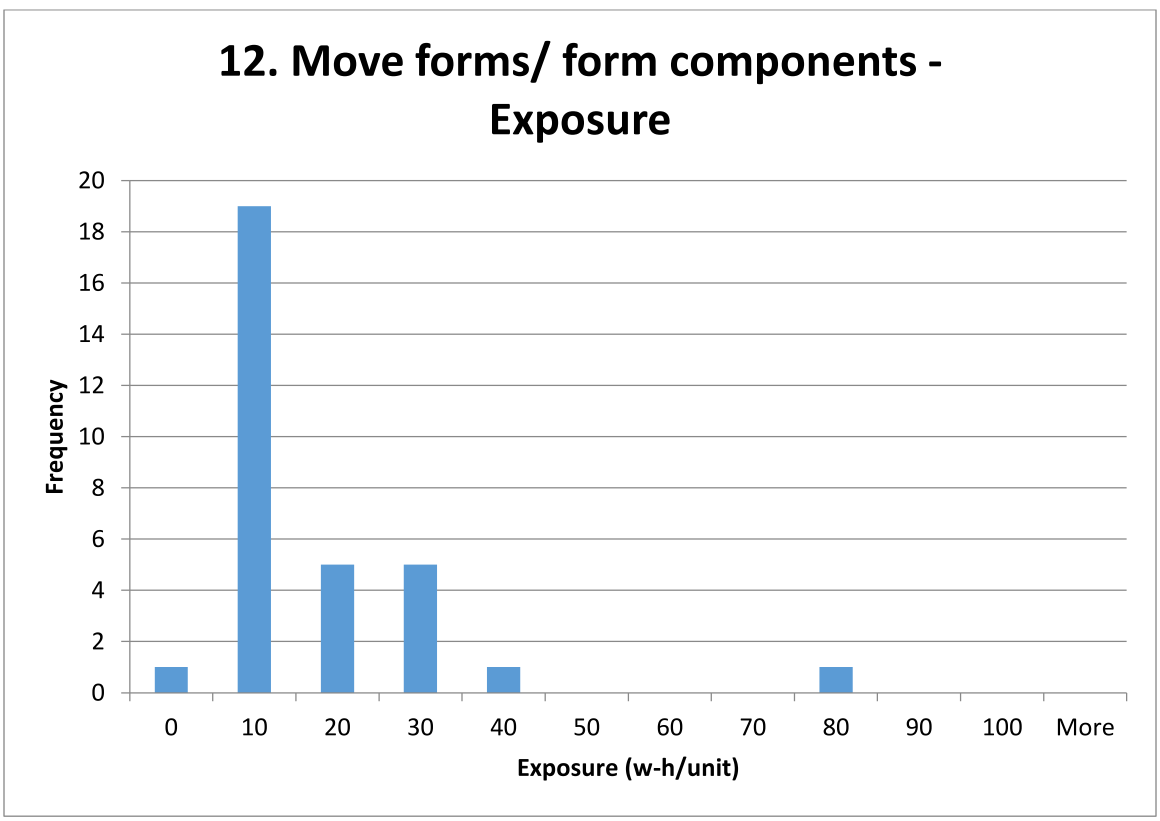

7. Erecting/ Placing Forms - Exposure
Frequency
10
9
8
7
6
5
4
3
2
1
0
0
10
20
30
40
50
60
70
80
90
100
More
Exposure (w-h/unit)

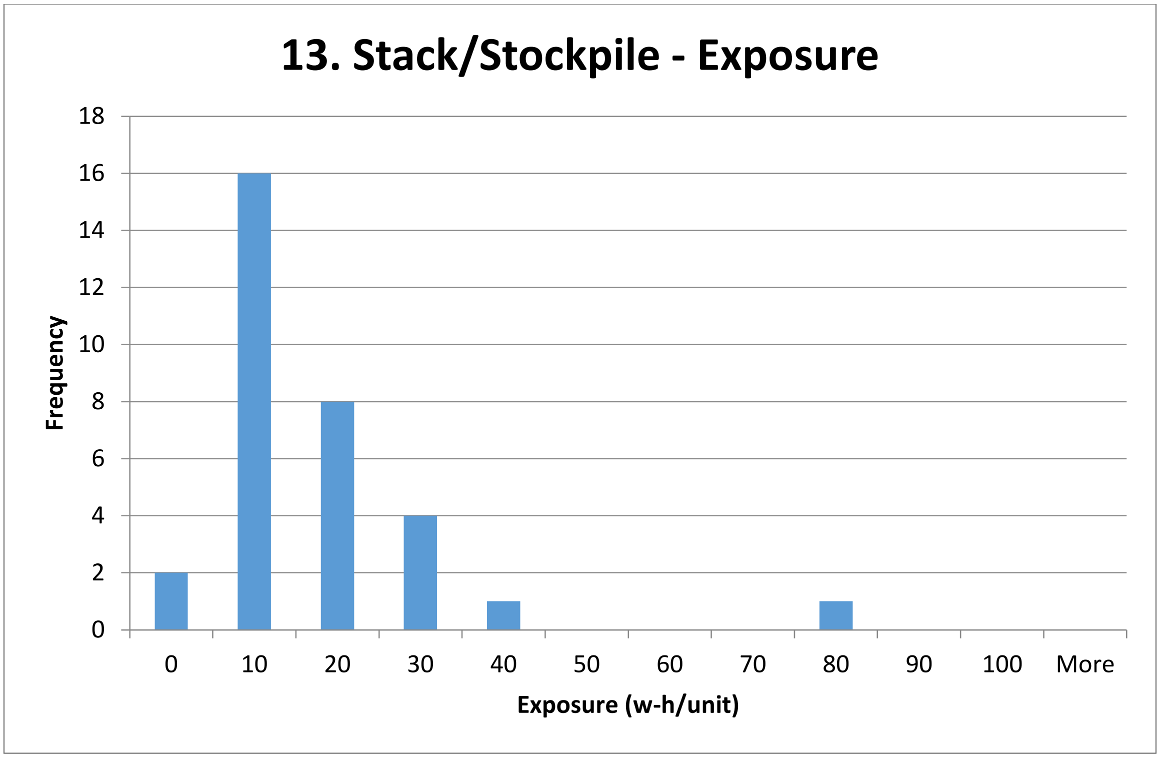

8. Pouring/ Curing Concrete - Exposure
Frequency
18
16
14
12
10
8
6
4
2
0
0
10
20
30
40
50
60
70
80
90
100
More
Exposure (w-h/unit)


9. Stripping forms - Exposure
Frequency
12
10
8
6
4
2
0
0
10
20
30
40
50
60
70
80
90
100
More
Exposure (w-h/unit)


10.Move Forms - Exposure
Frequency
18
16
14
12
10
8
6
4
2
0
0
10
20
30
40
50
60
70
80
90
100
More
Exposure (w-h/unit)

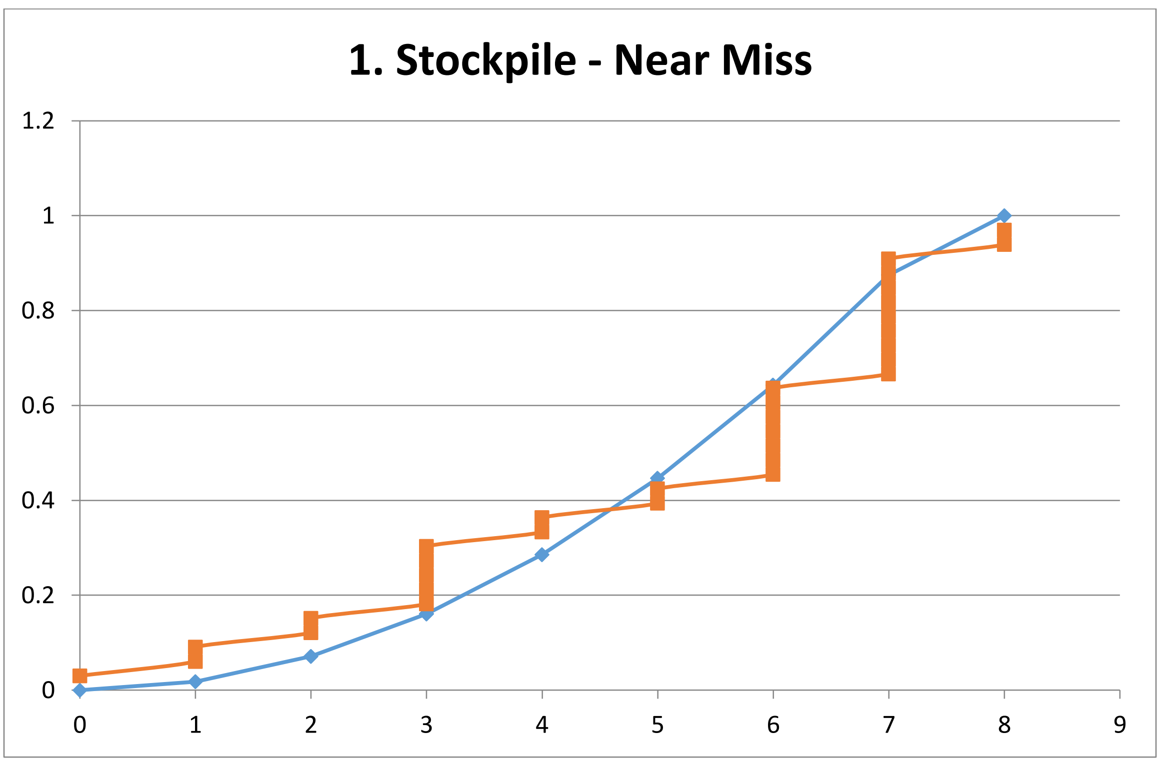

11. Dismantling/Cleaning forms - Exposure
Frequency
18
16
14
12
10
8
6
4
2
0
0
10
20
30
40
50
60
70
80
90
100
More
Exposure (w-h/unit)

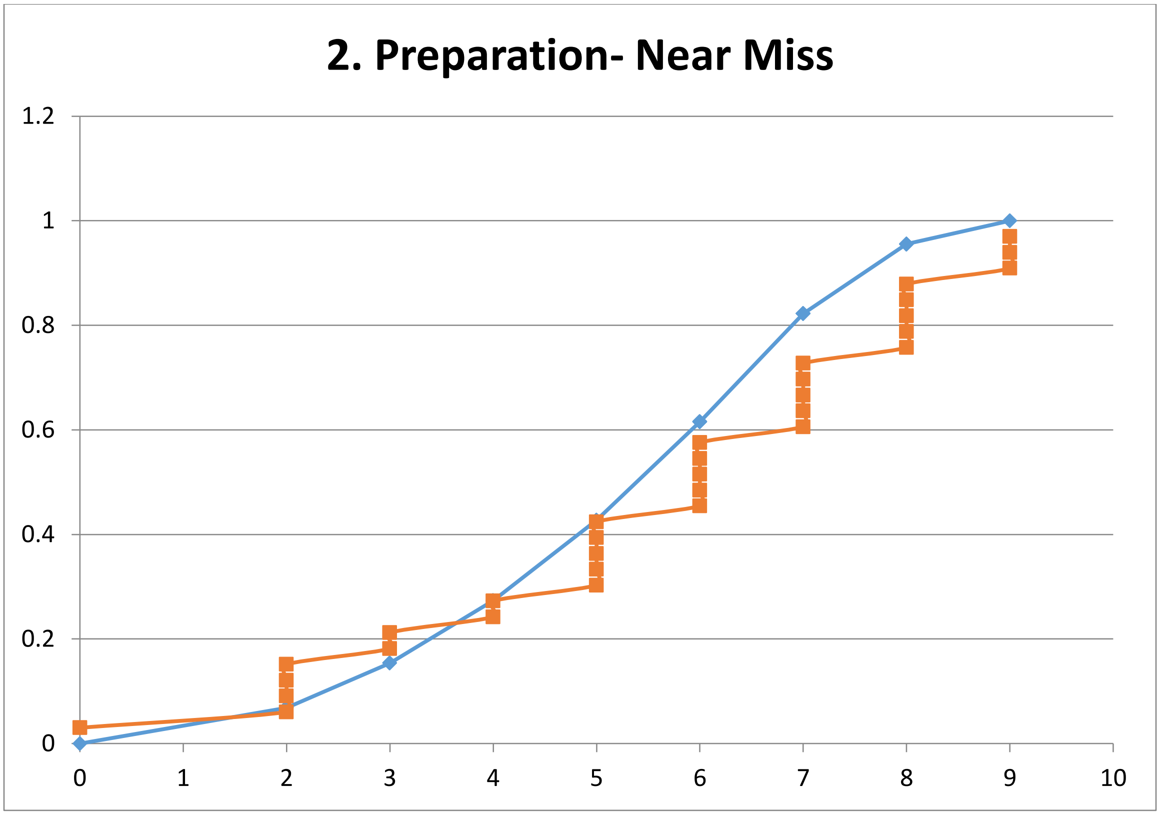

12. Move forms/ form components - Exposure
Frequency
20
18
16
14
12
10
8
6
4
2
0
0
10
20
30
40
50
60
70
80
90
100
More
Exposure (w-h/unit)

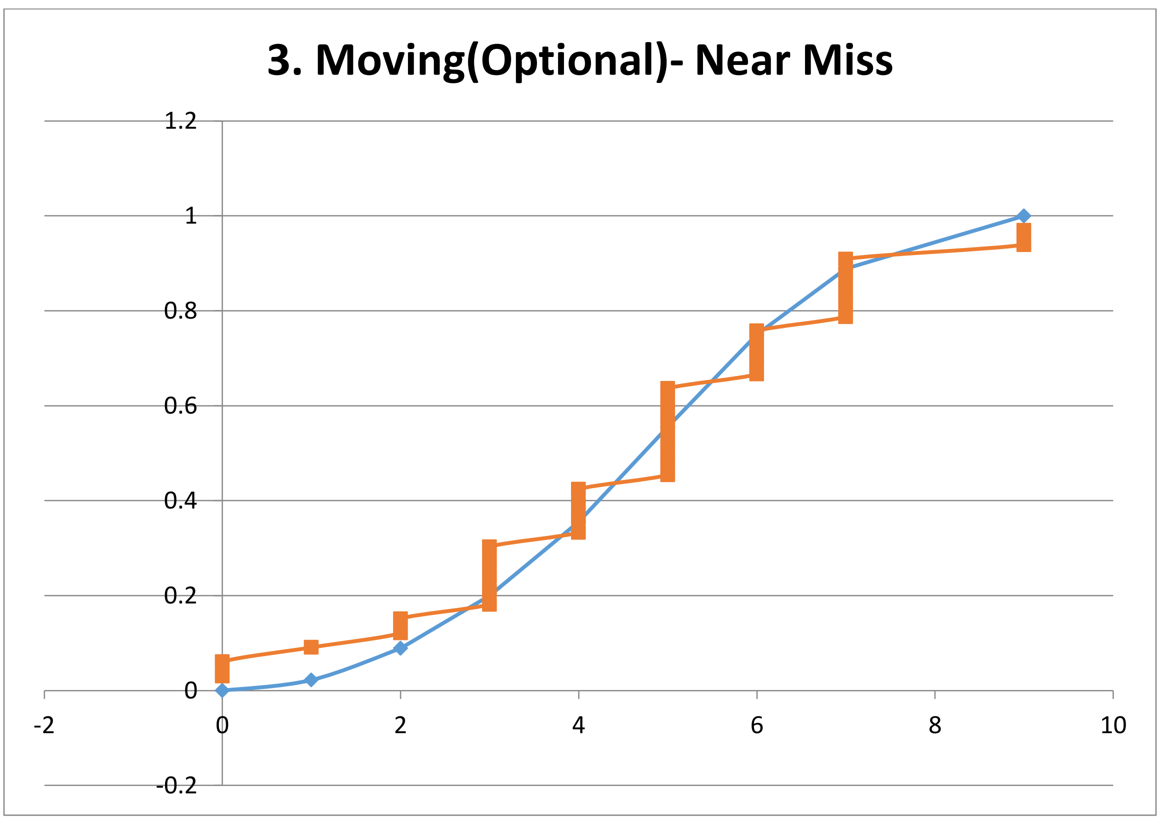


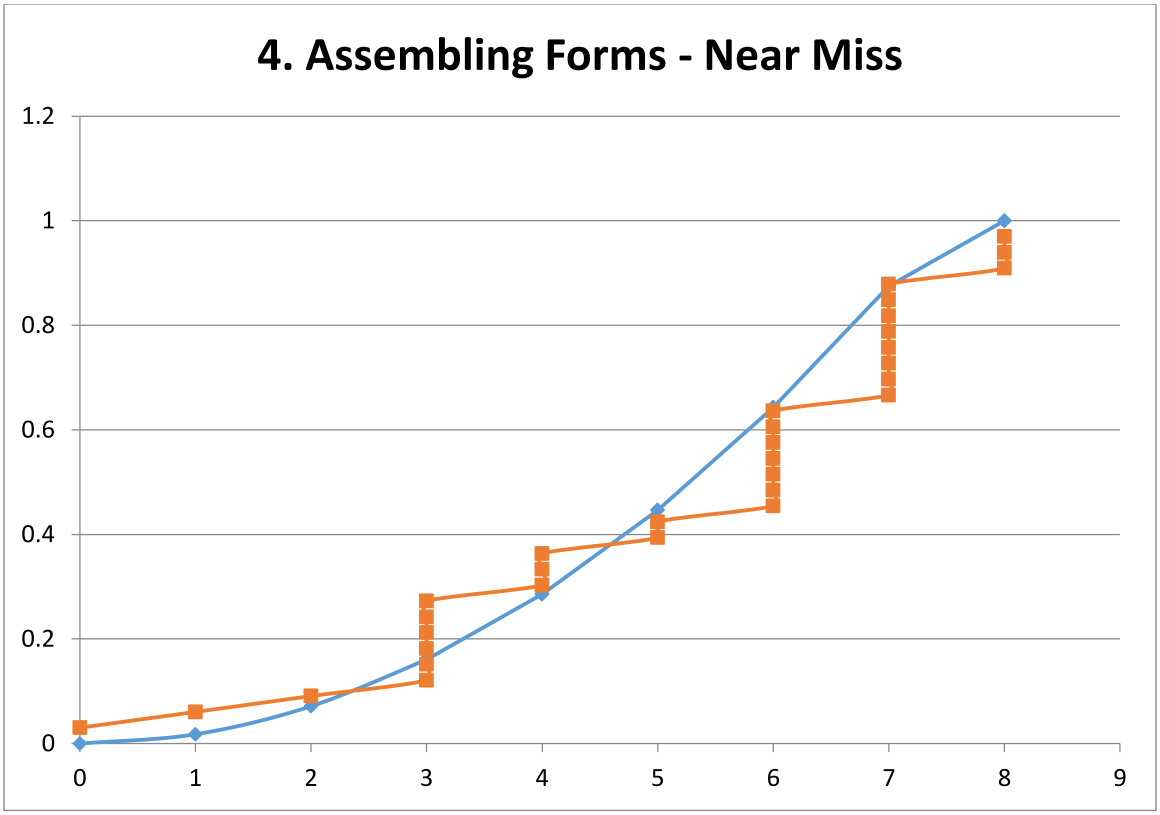
APPENDIX – III D: CDF PLOTS

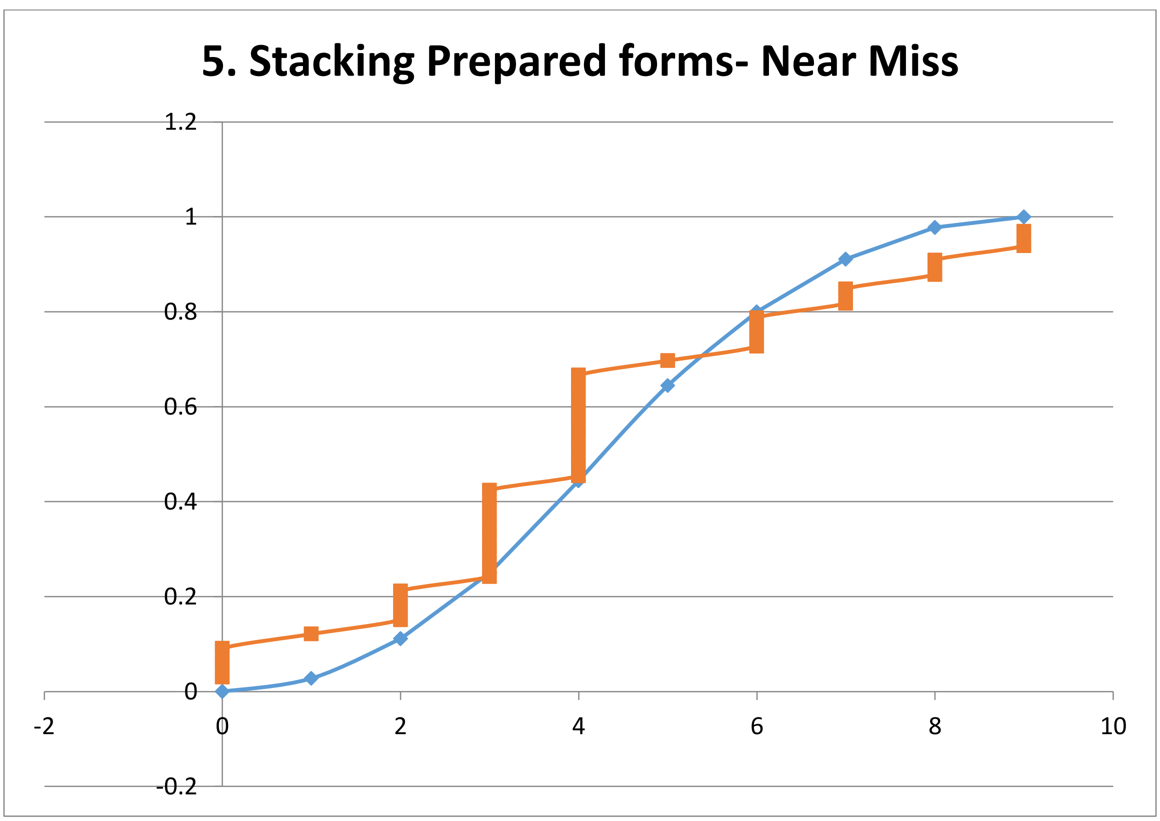
CDF Plots for Near Miss: Triangular distribution

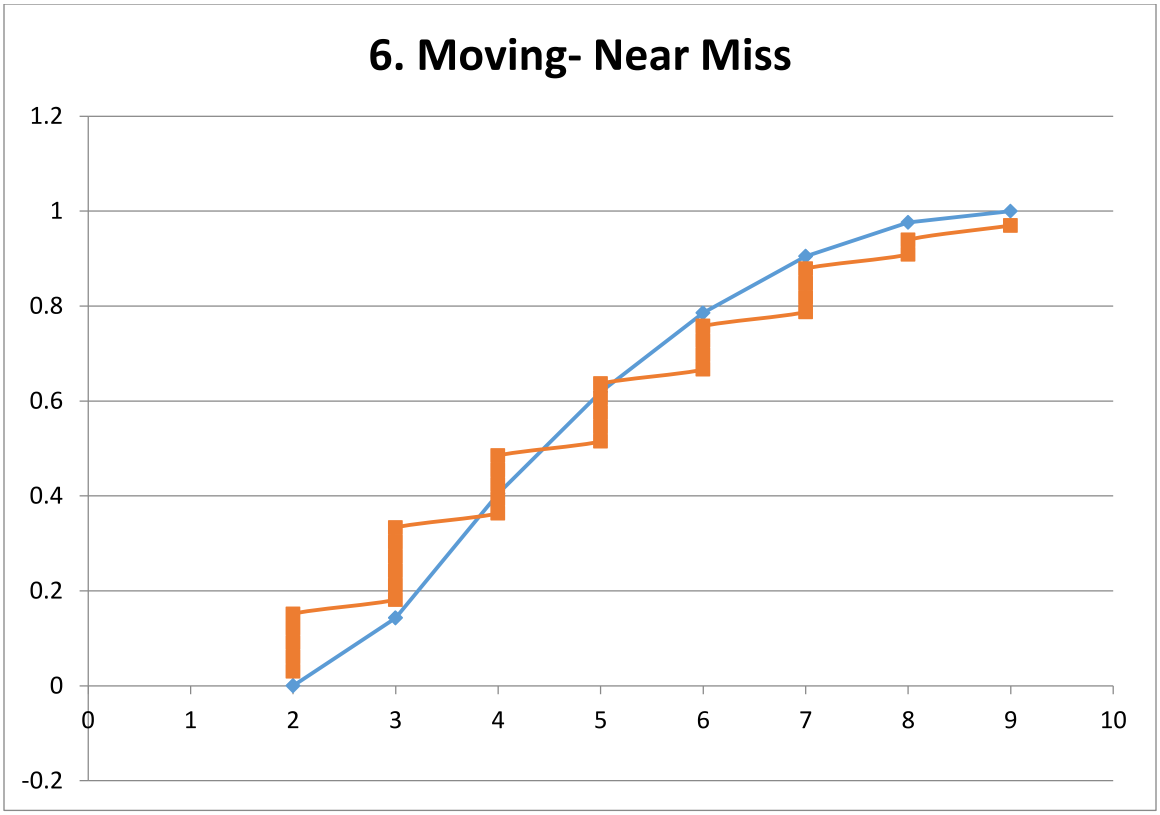


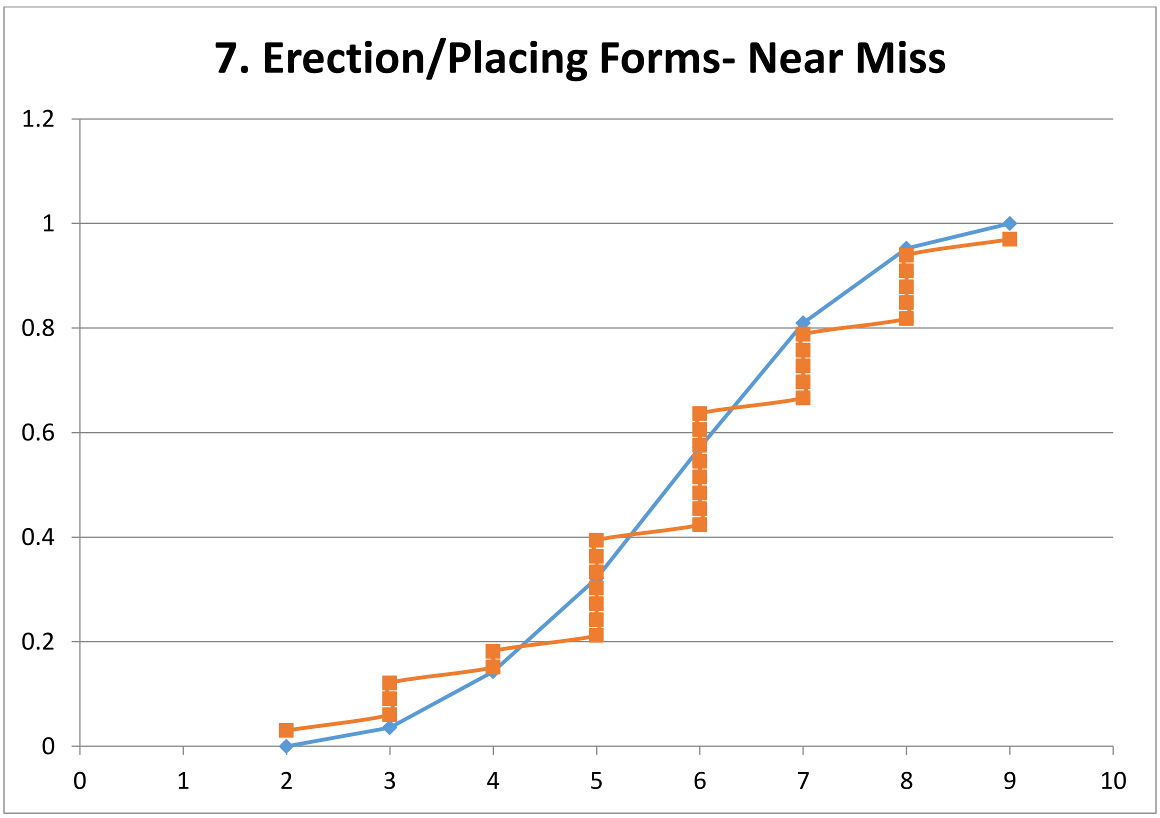

2. Preparation- Near Miss
1.2
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5
6
7
8
9
10

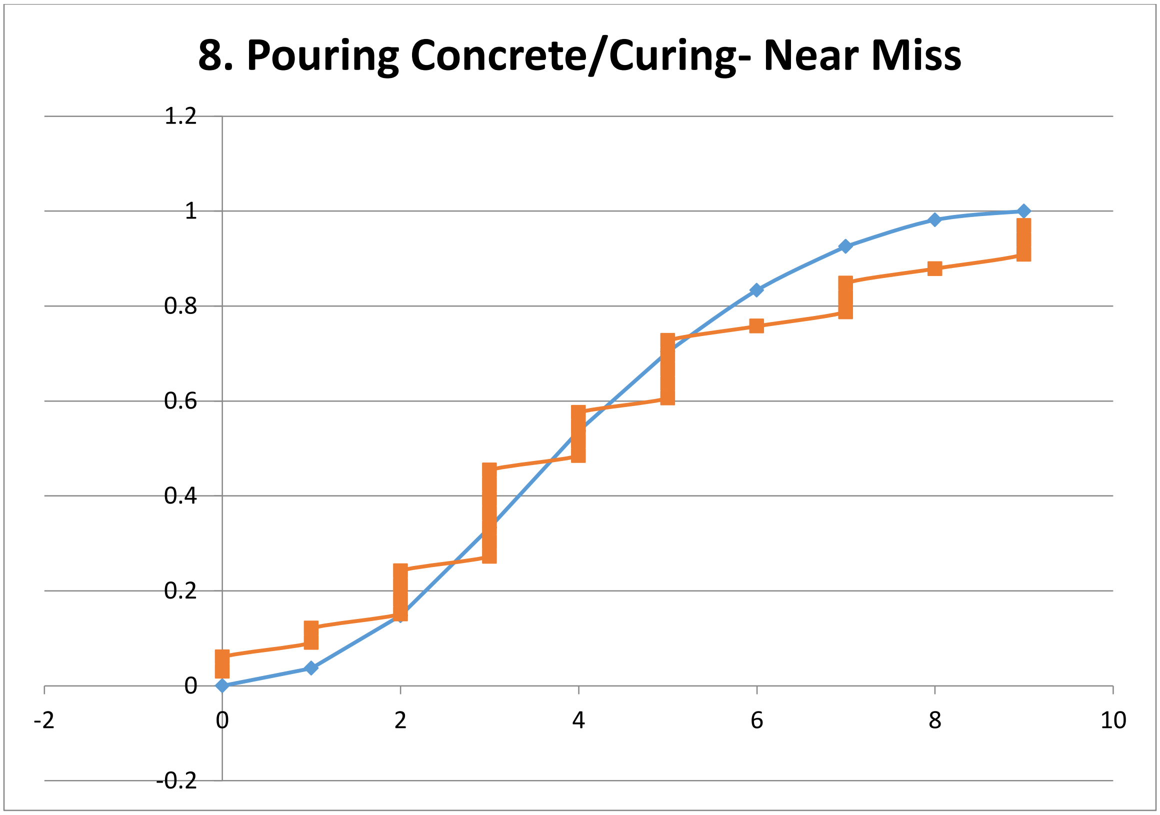

3. Moving(Optional)- Near Miss
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-2
0
2
4
6
8
10

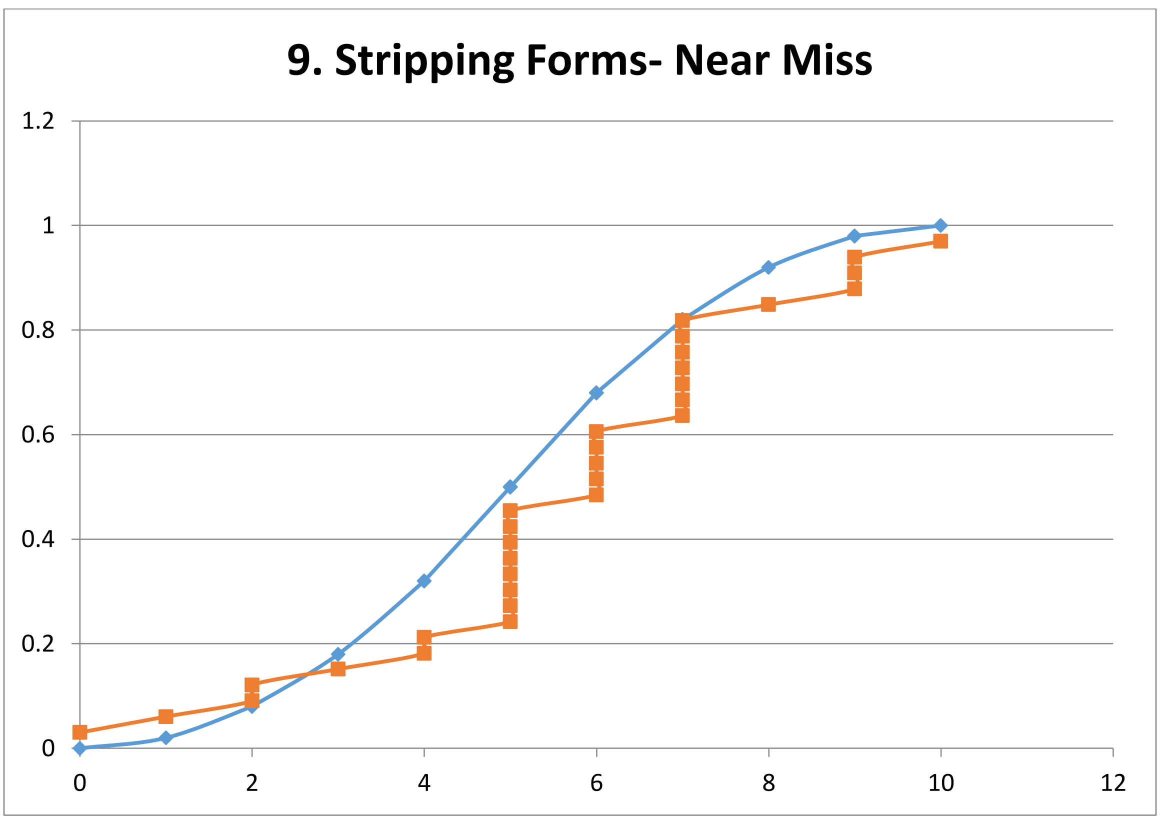

4. Assembling Forms - Near Miss
1.2
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5
6
7
8
9

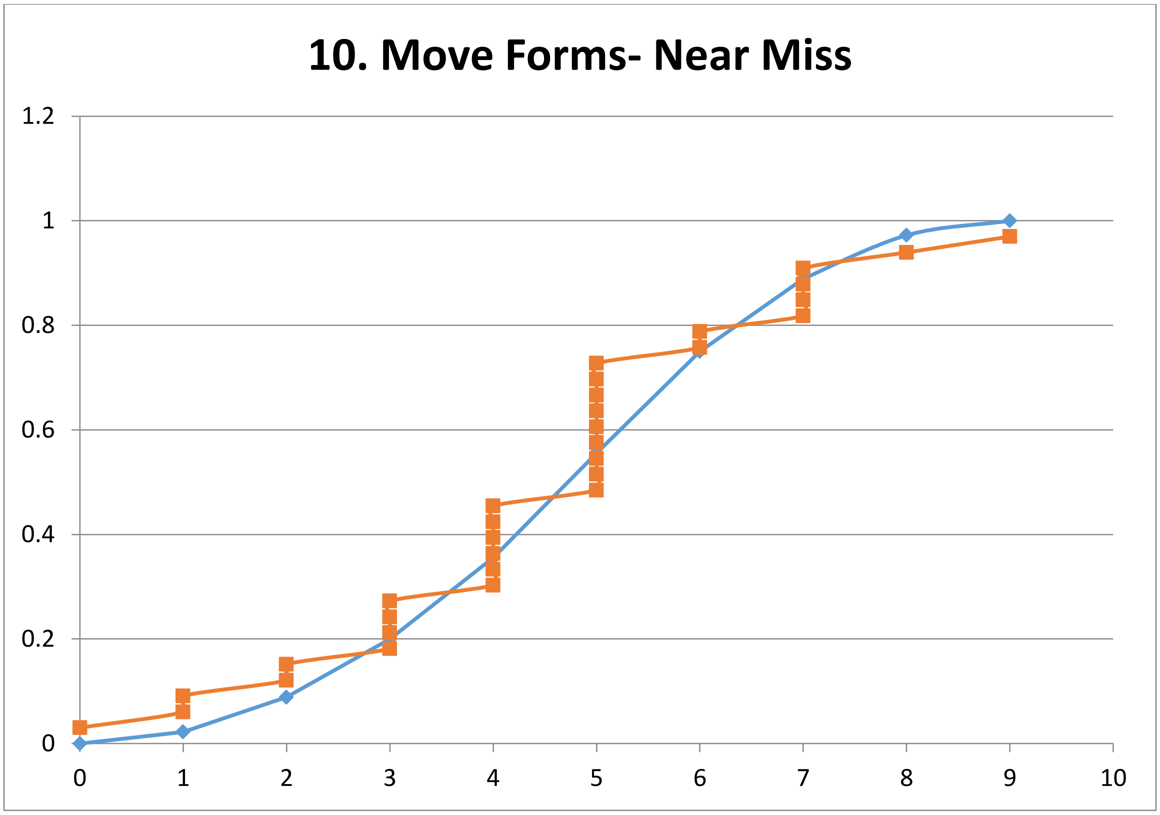

5. Stacking Prepared forms- Near Miss
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-2
0
2
4
6
8
10

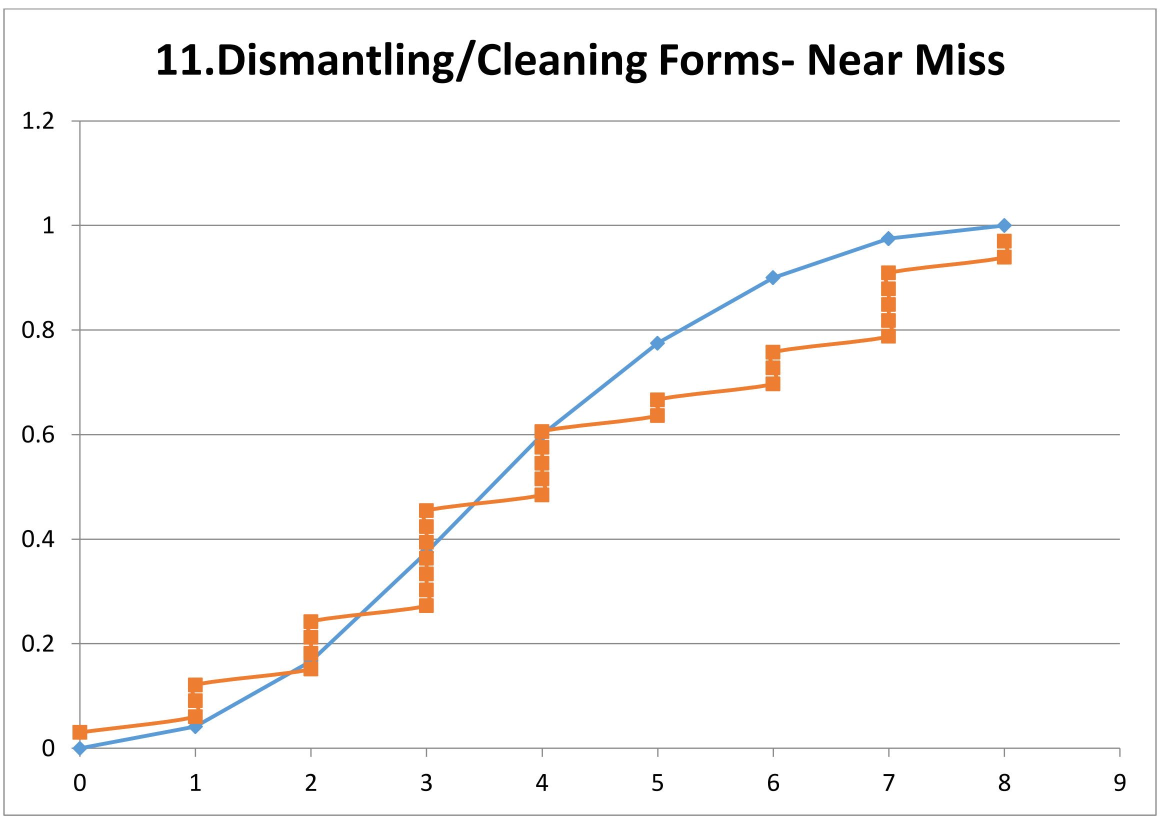

6. Moving- Near Miss
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0 1 2 3 4 5 6 7 8 9 10

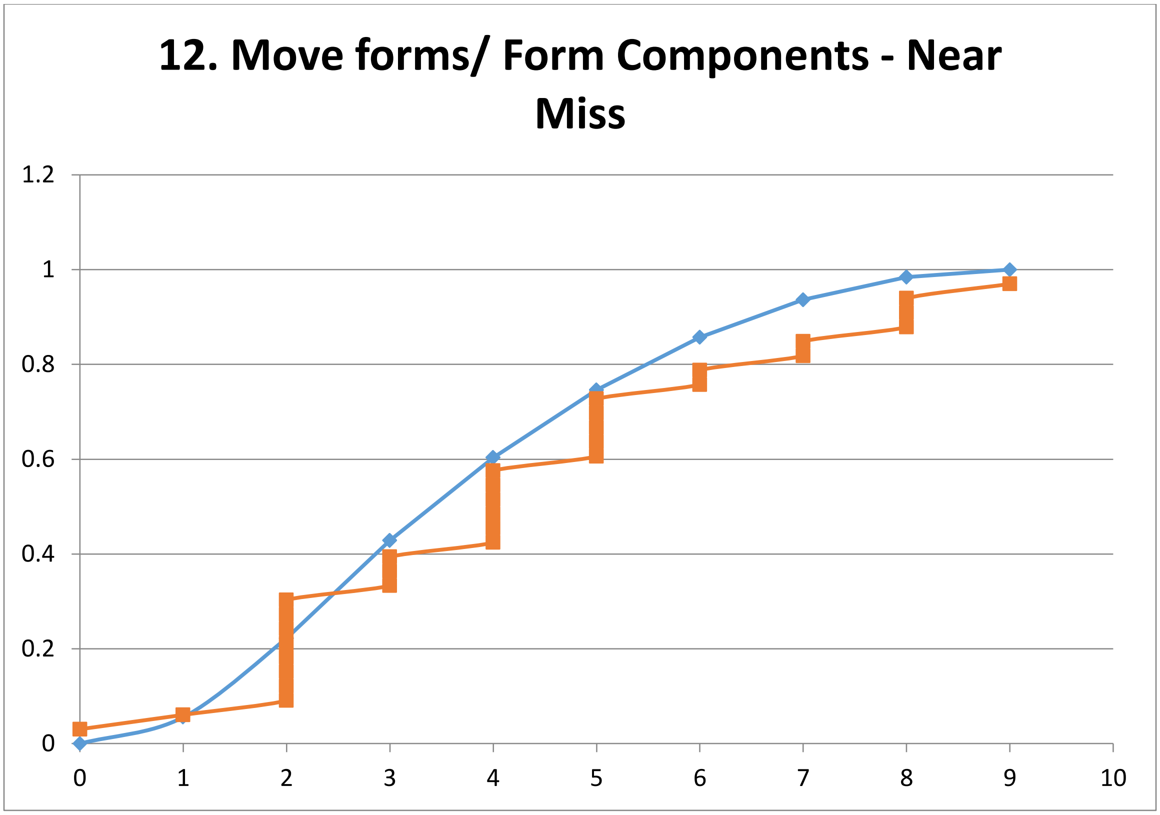

7. Erection/Placing Forms- Near Miss
1.2
1
0.8
0.6
0.4
0.2
0
0 1 2 3 4 5 6 7 8 9 10

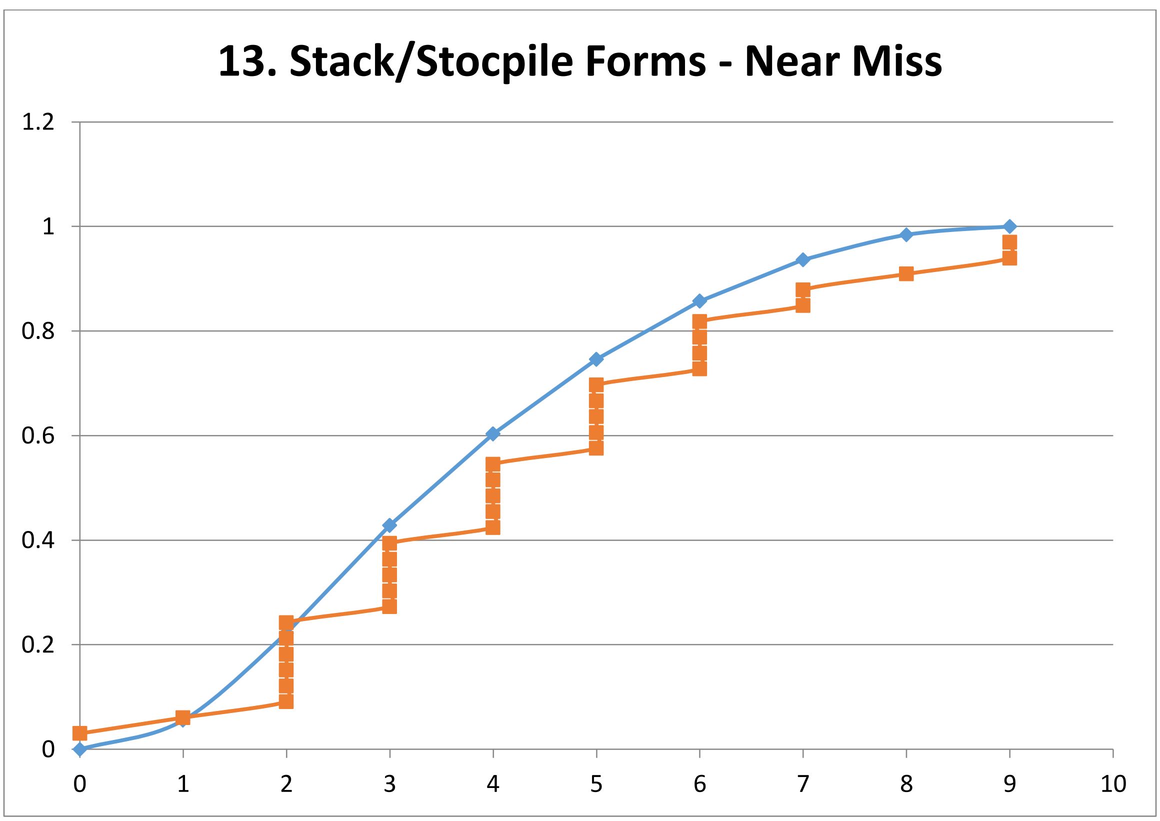

8. Pouring Concrete/Curing- Near Miss
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-2
0
2
4
6
8
10


9. Stripping Forms- Near Miss
1.2
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10
12

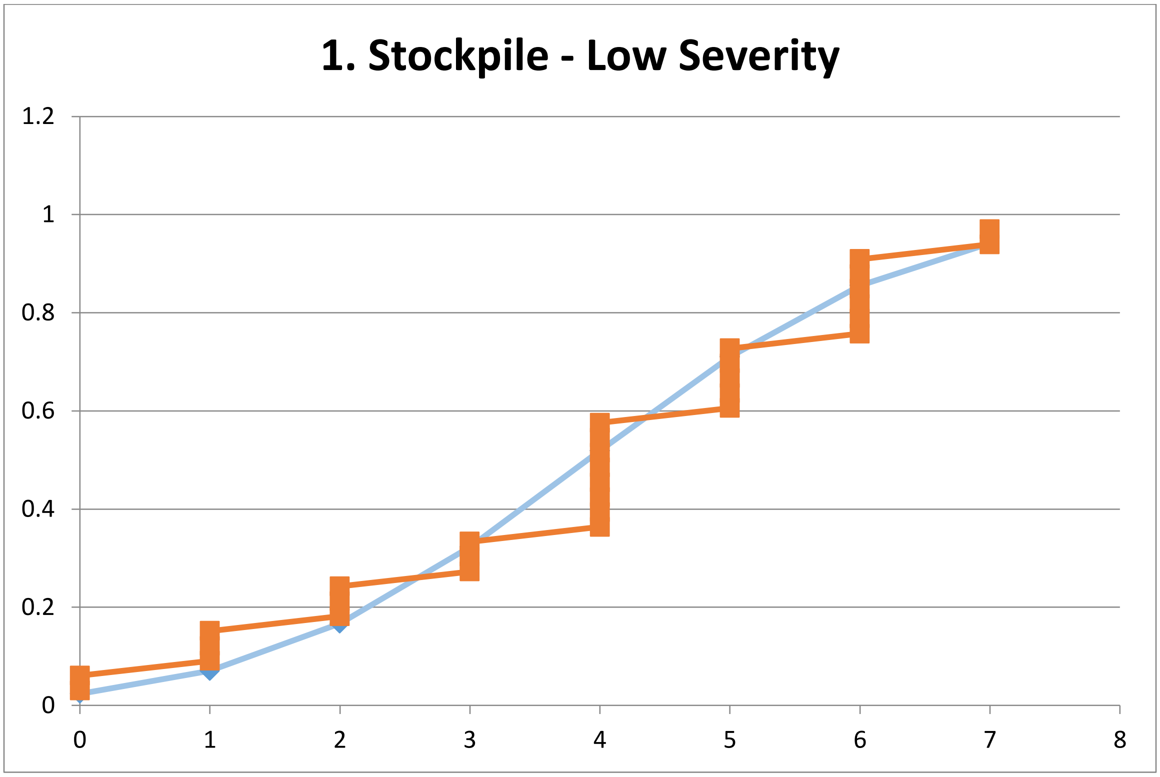

10. Move Forms- Near Miss
1.2
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5
6
7
8
9
10

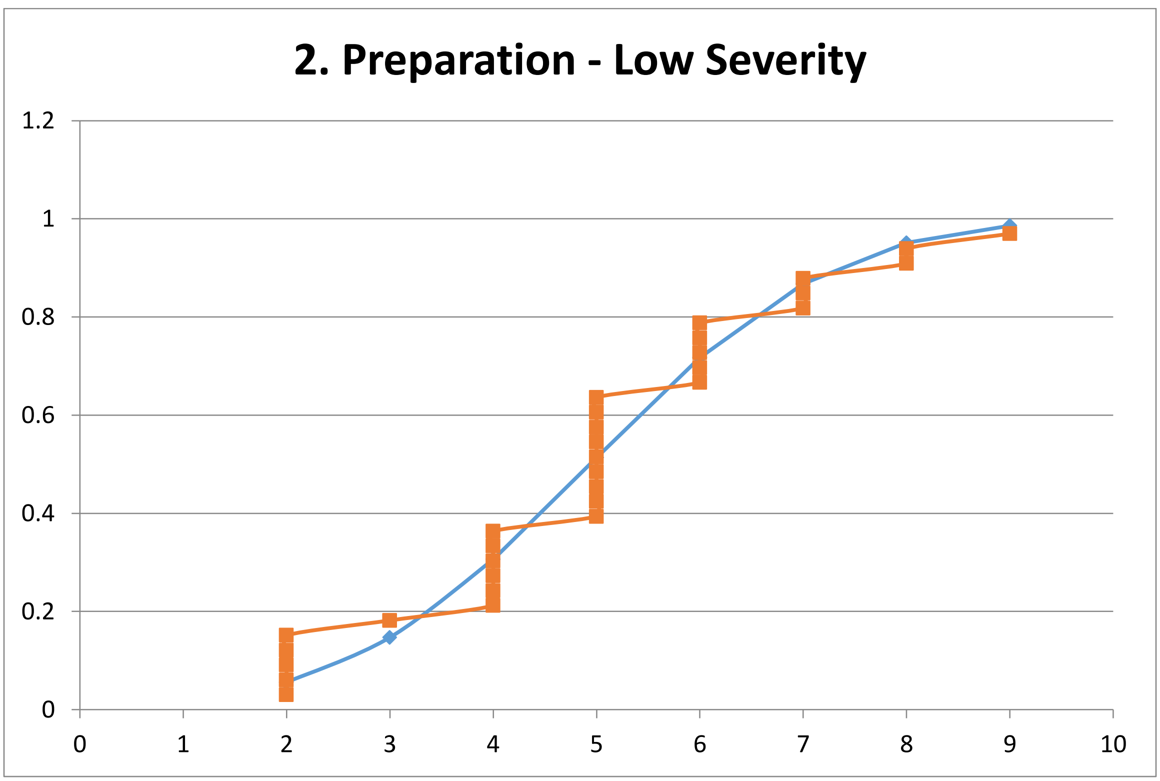

11.Dismantling/Cleaning Forms- Near Miss
1.2
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5
6
7
8
9

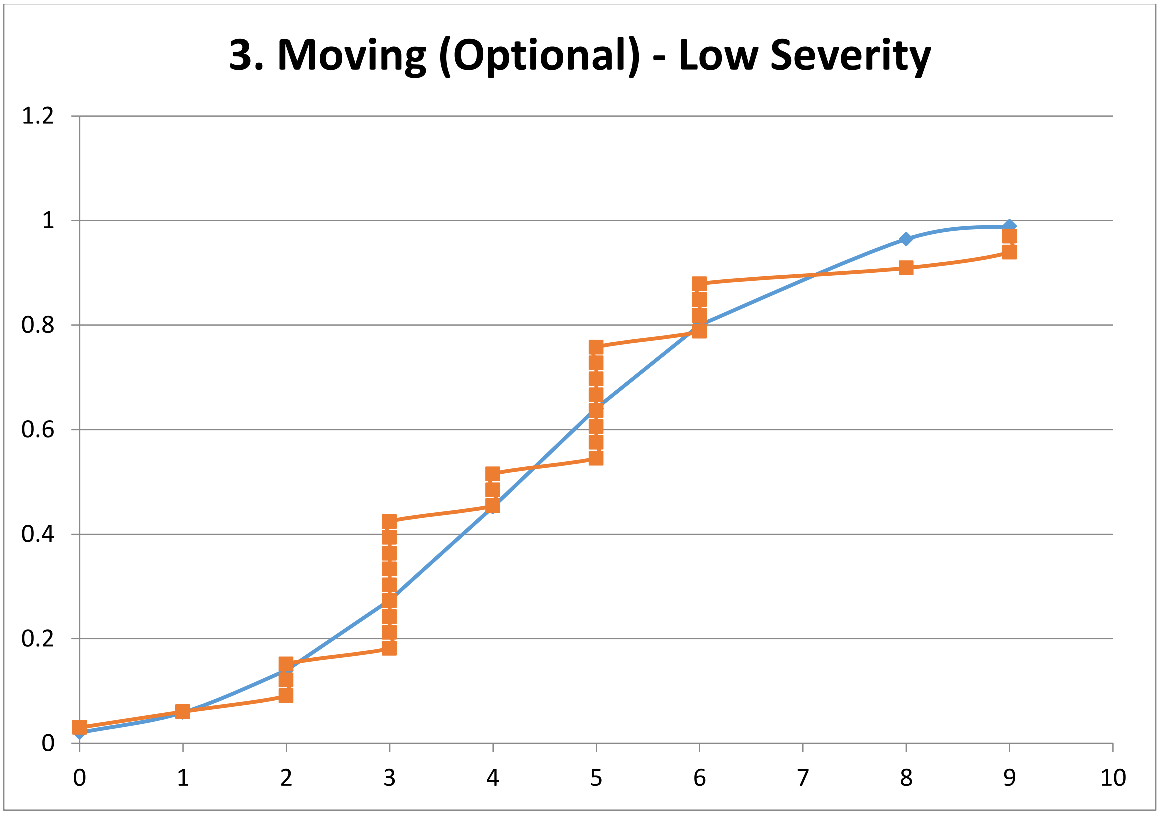

12. Move forms/ Form Components - Near Miss
1.2
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5
6
7
8
9
10

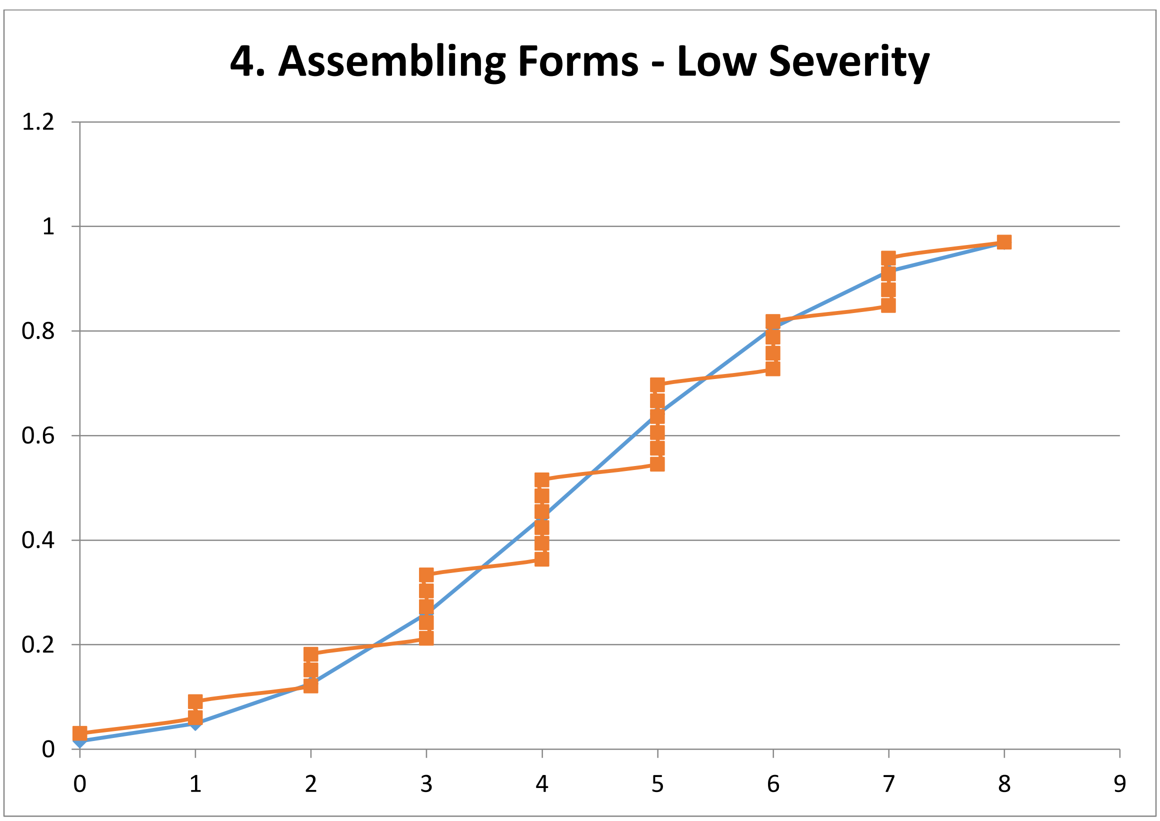

13. Stack/Stocpile Forms - Near Miss
1.2
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5
6
7
8
9
10

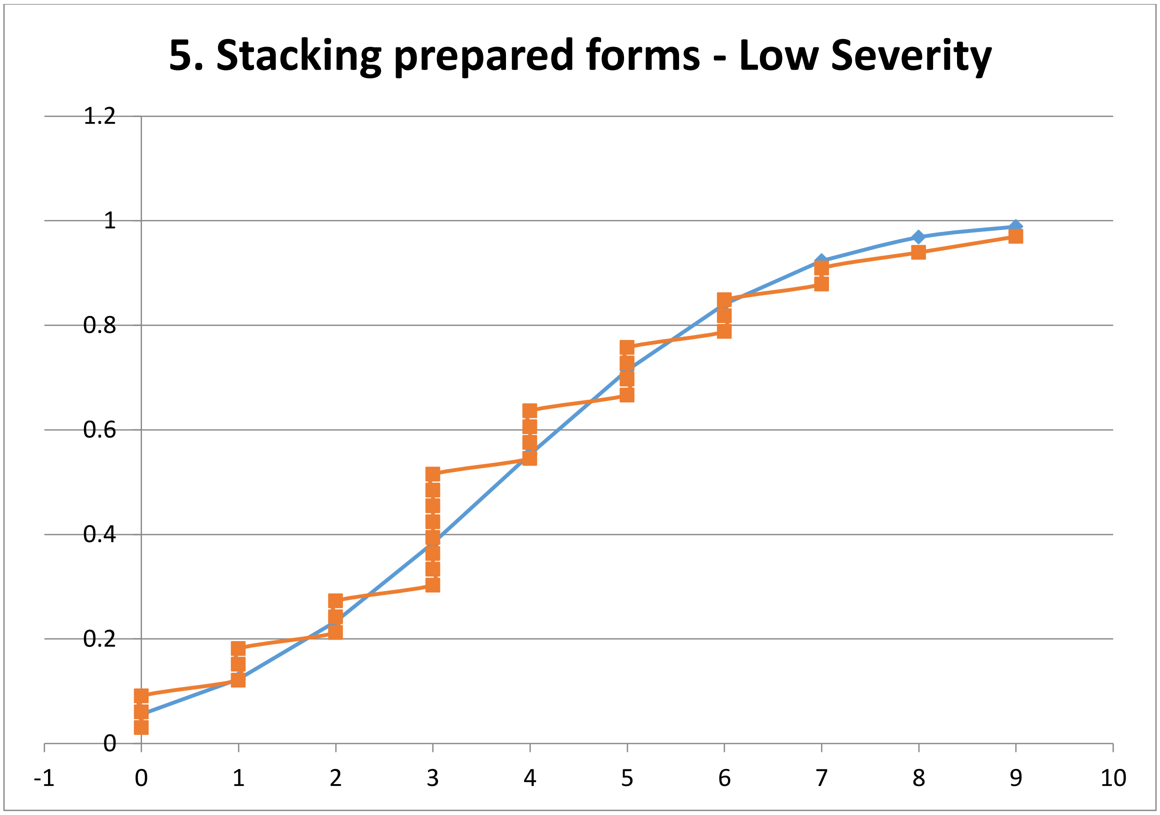
CDF Plots for Low Severity: Normal distribution

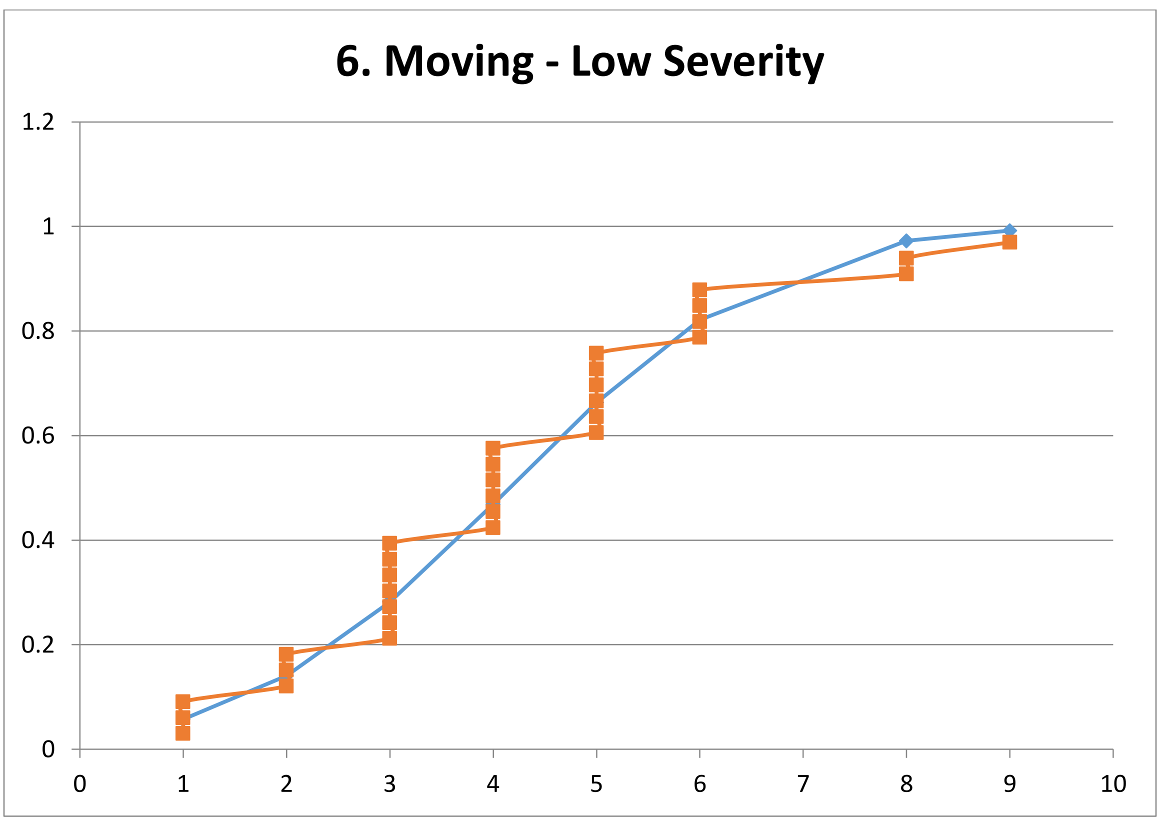


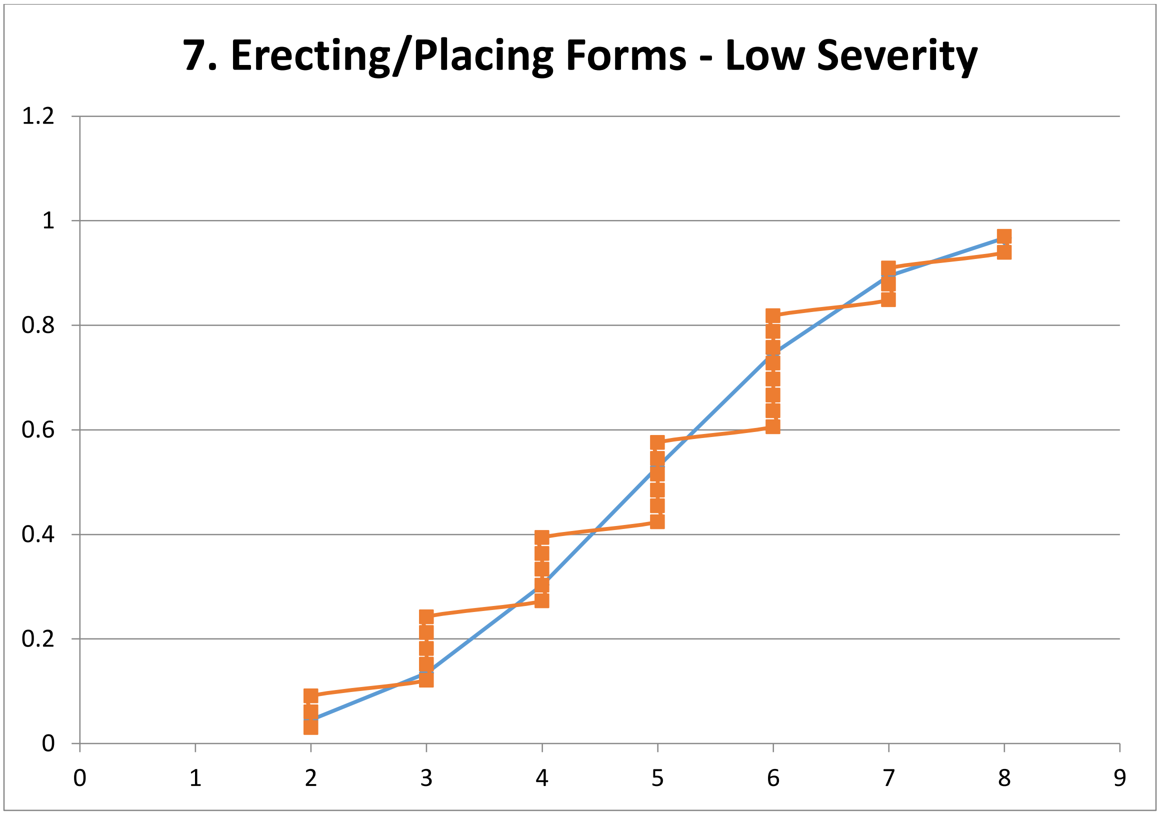


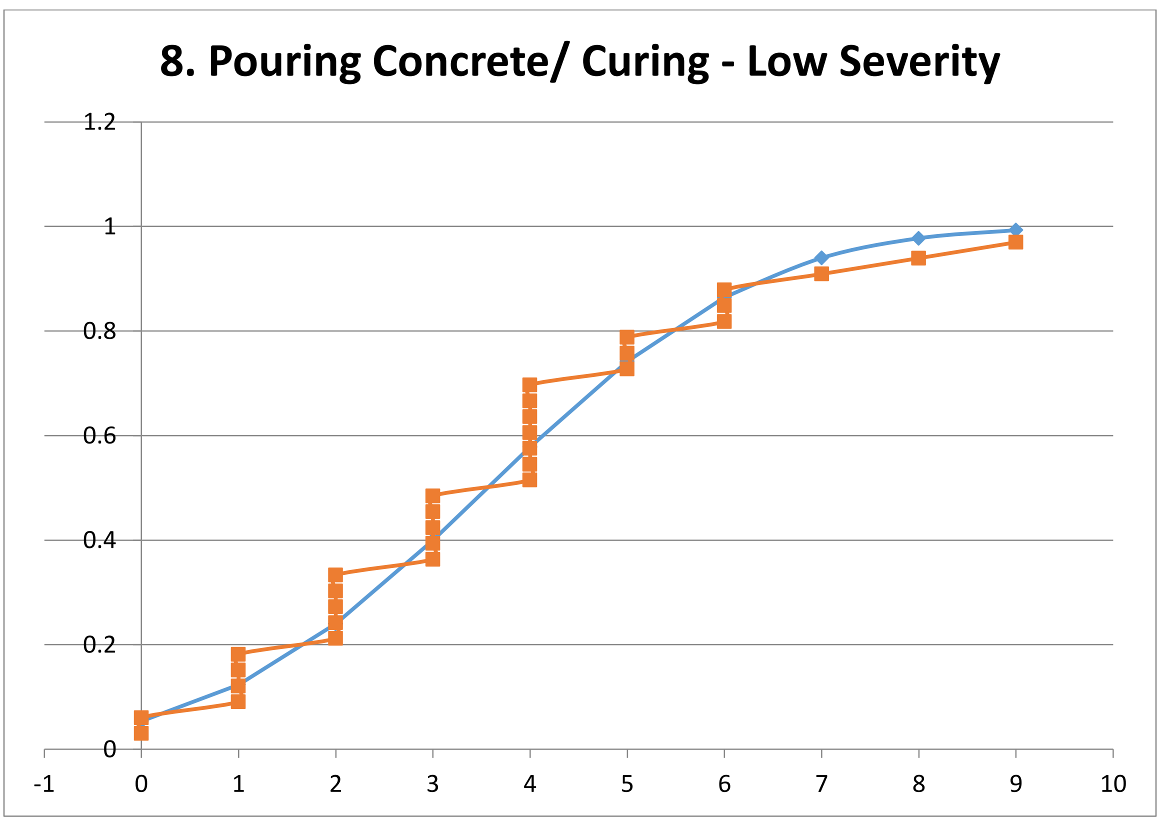

3. Moving (Optional) - Low Severity
1.2
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5
6
7
8
9
10

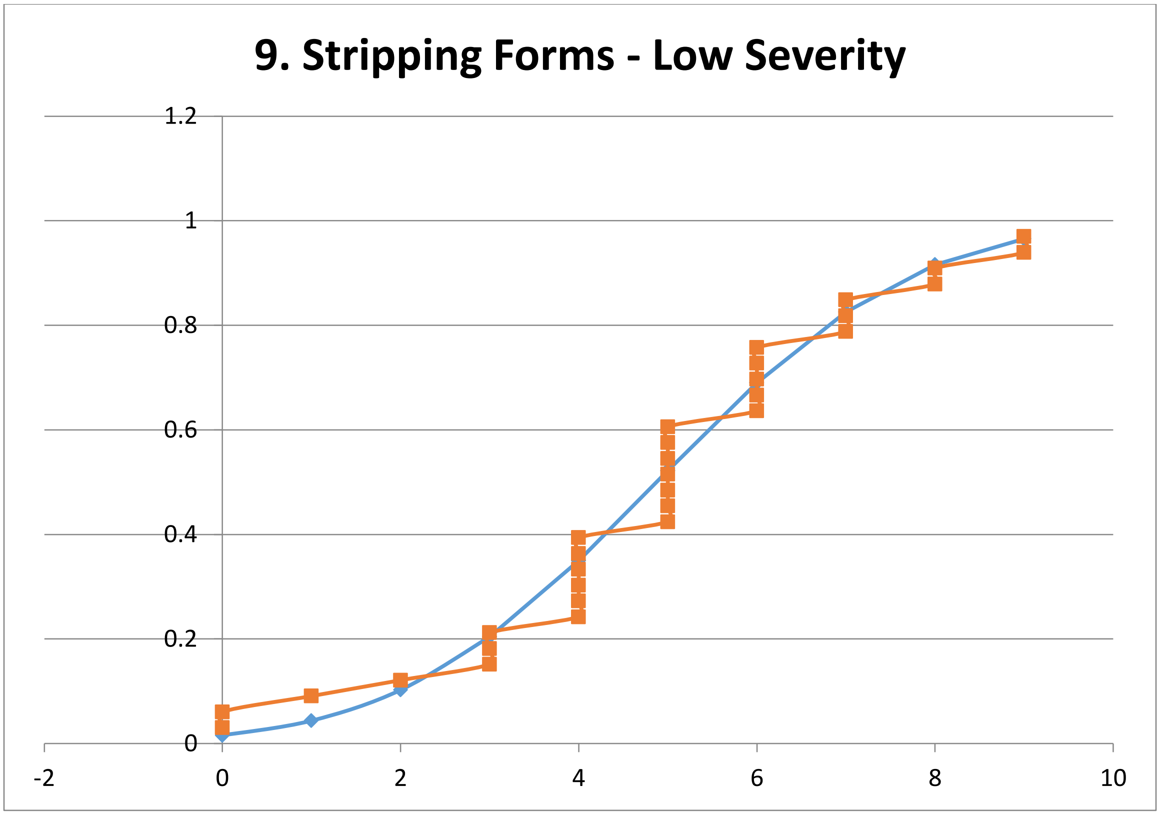

4. Assembling Forms - Low Severity
1.2
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5
6
7
8
9

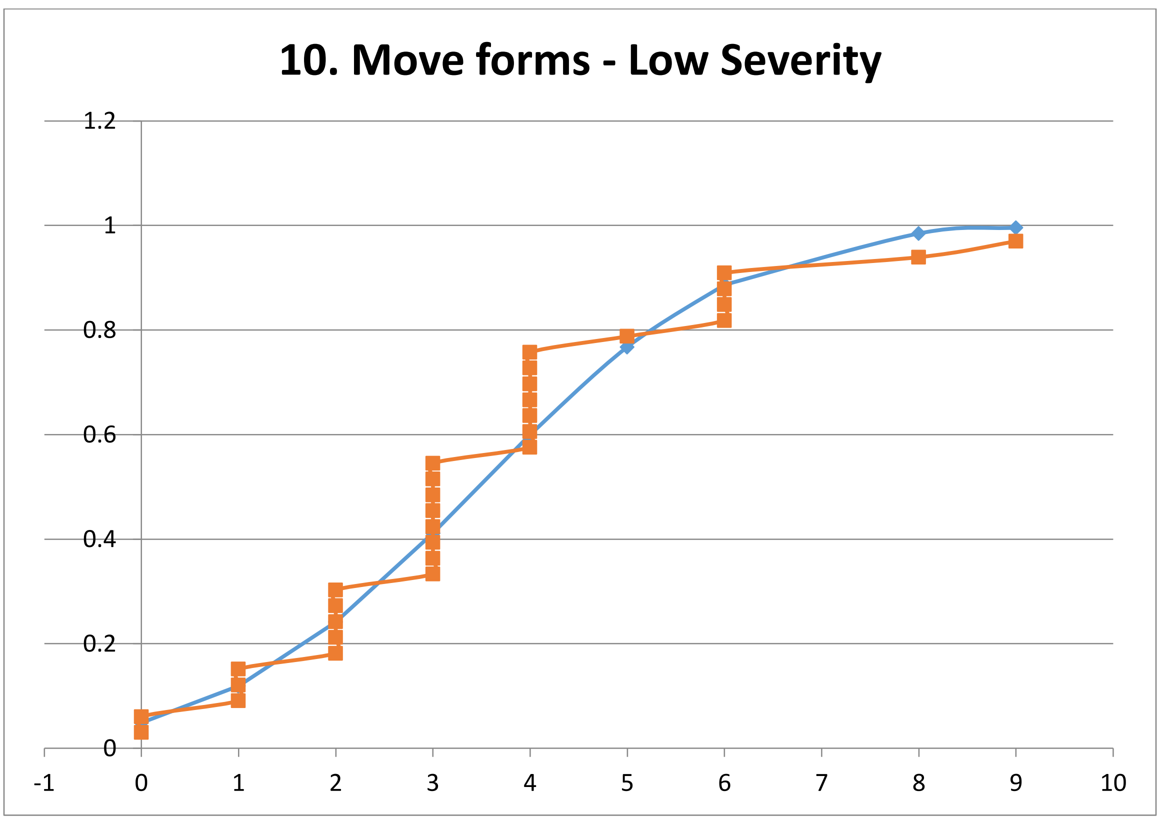

5. Stacking prepared forms - Low Severity
1.2
1
0.8
0.6
0.4
0.2
0
-1
0
1
2
3
4
5
6
7
8
9
10

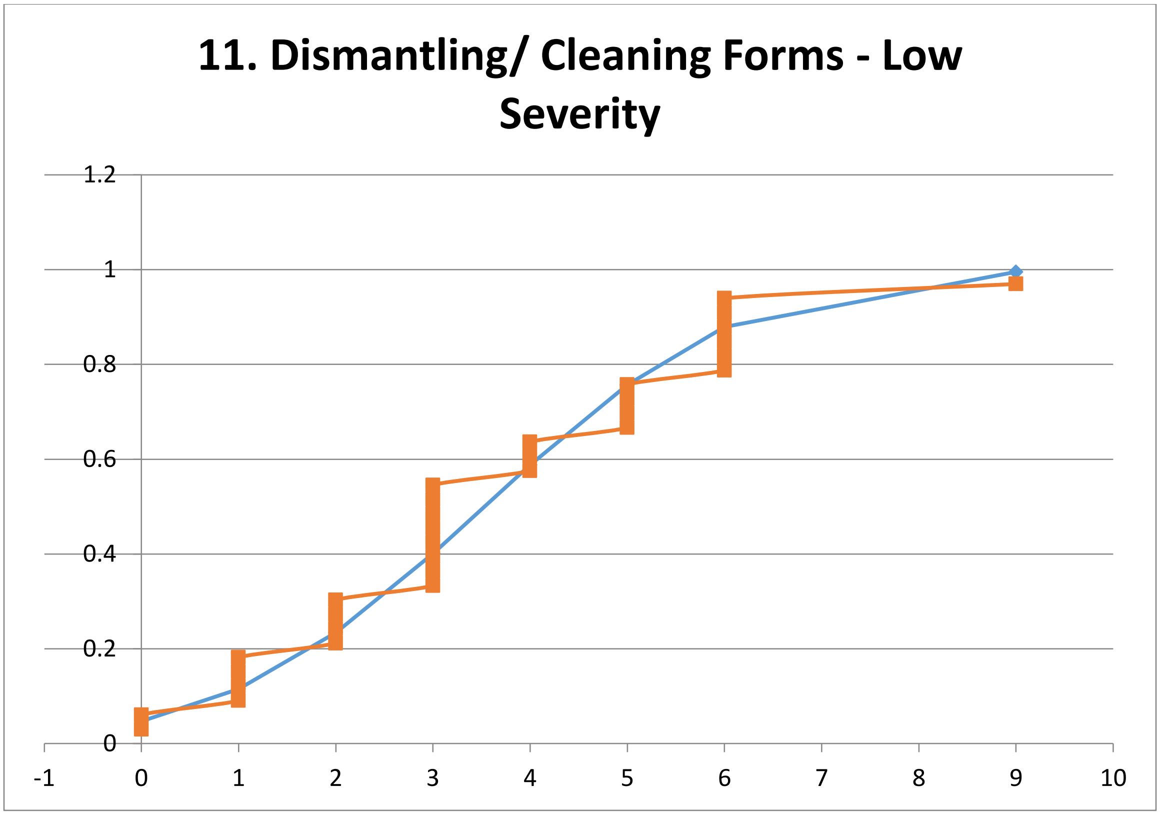

6. Moving - Low Severity
1.2
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5
6
7
8
9
10

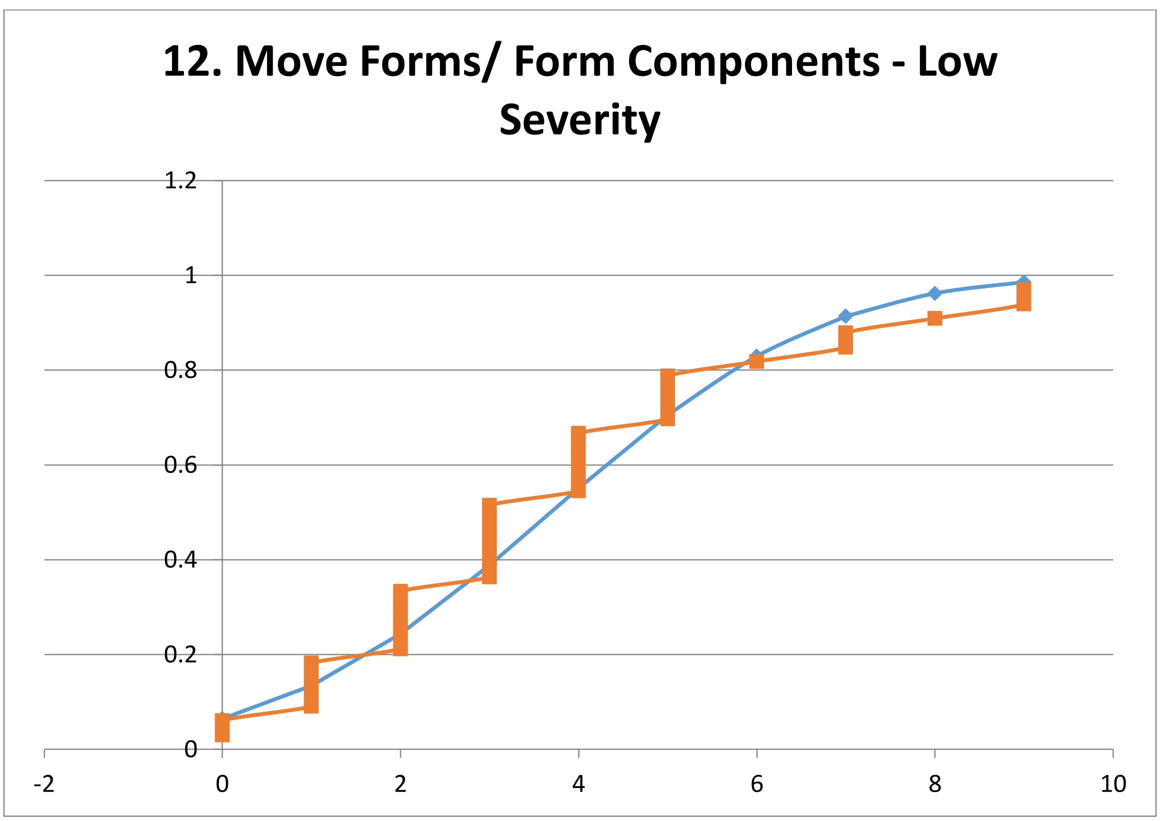

7. Erecting/Placing Forms - Low Severity
1.2
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5
6
7
8
9

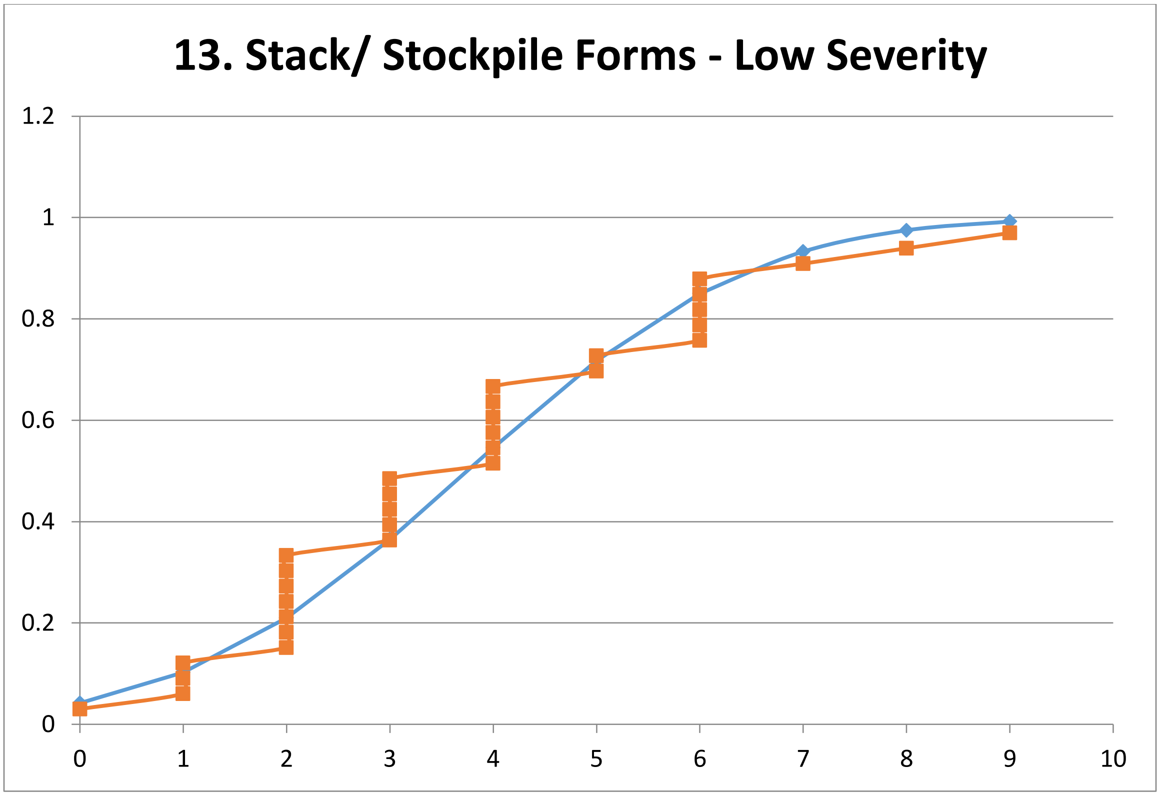

8. Pouring Concrete/ Curing - Low Severity
1.2
1
0.8
0.6
0.4
0.2
0
-1
0
1
2
3
4
5
6
7
8
9
10


9. Stripping Forms - Low Severity
1.2
1
0.8
0.6
0.4
0.2
0
-2
0
2
4
6
8
10

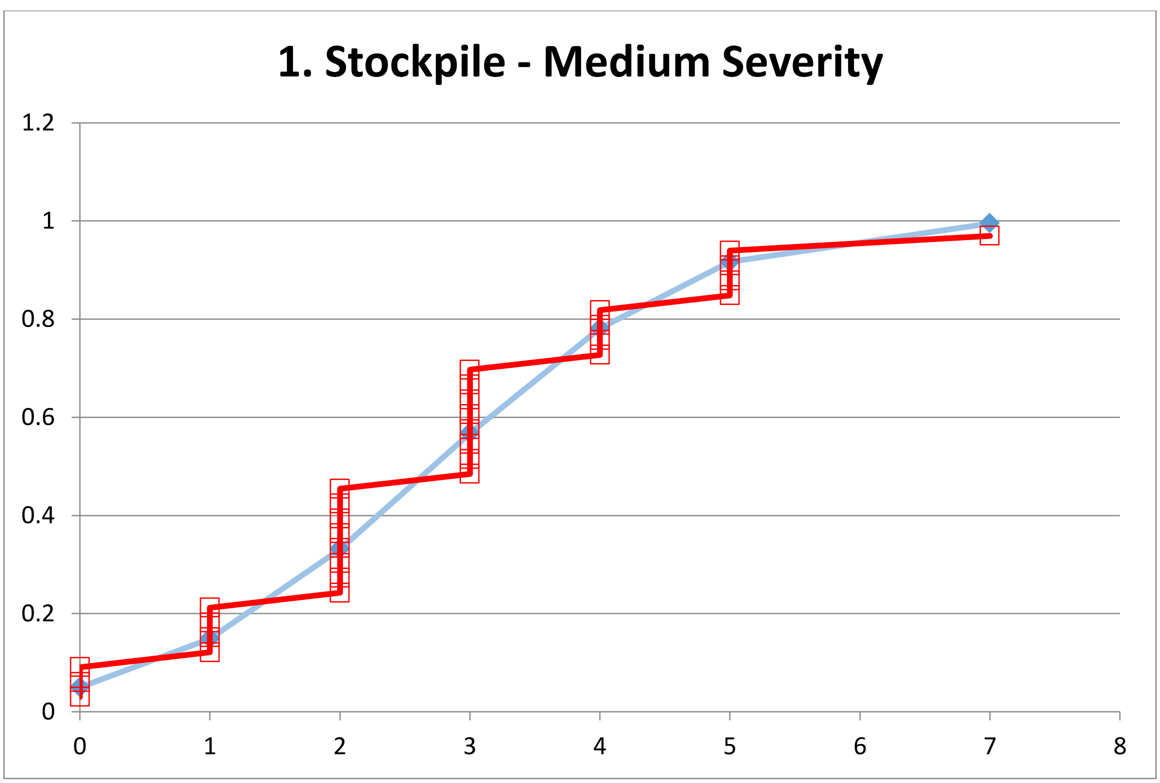

10. Move forms - Low Severity
1.2
1
0.8
0.6
0.4
0.2
0
-1
0
1
2
3
4
5
6
7
8
9
10

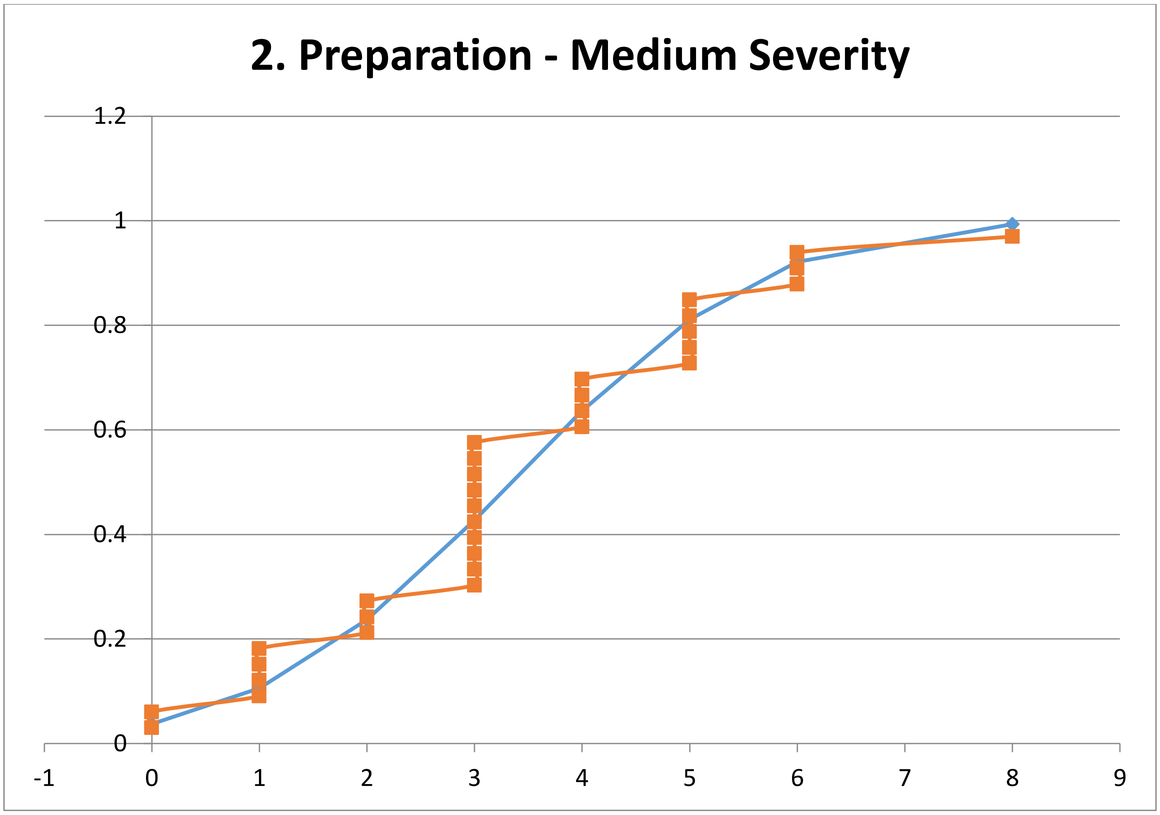

11. Dismantling/ Cleaning Forms - Low Severity
1.2
1
0.8
0.6
0.4
0.2
0
-1
0
1
2
3
4
5
6
7
8
9
10

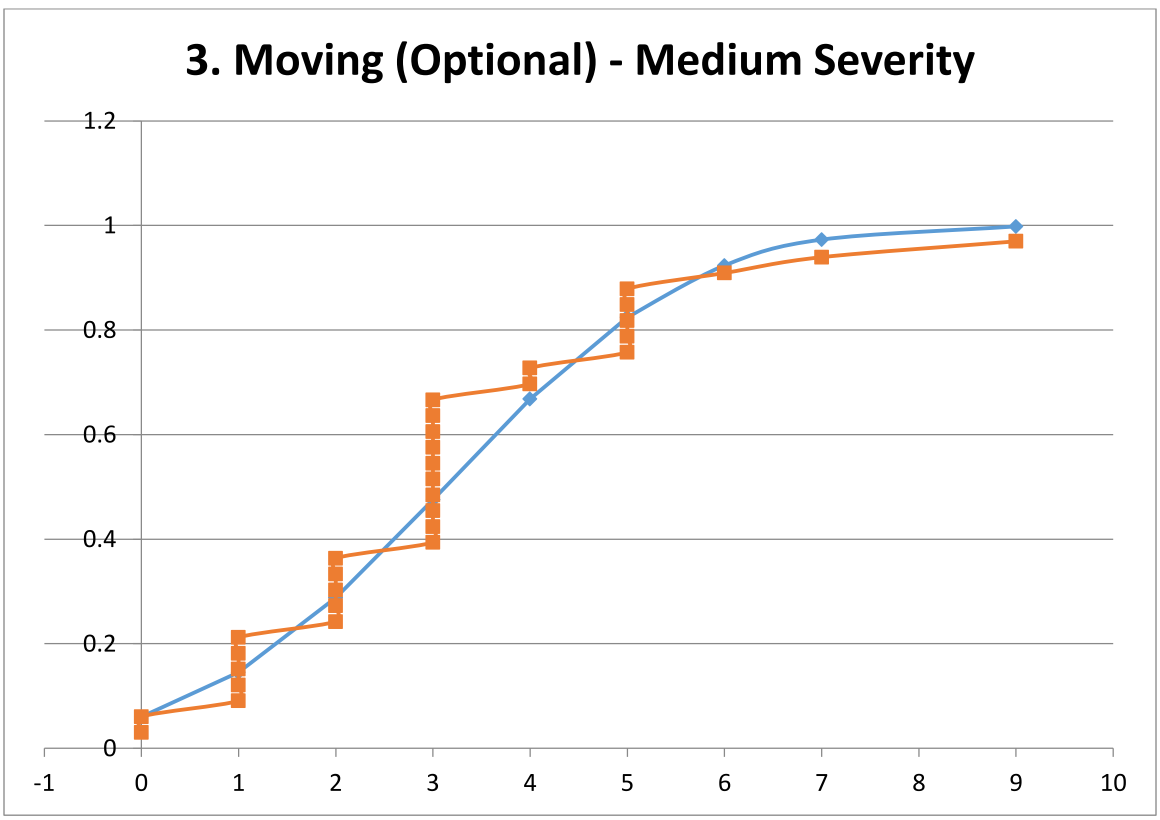

12. Move Forms/ Form Components - Low Severity
1.2
1
0.8
0.6
0.4
0.2
0
-2
0
2
4
6
8
10

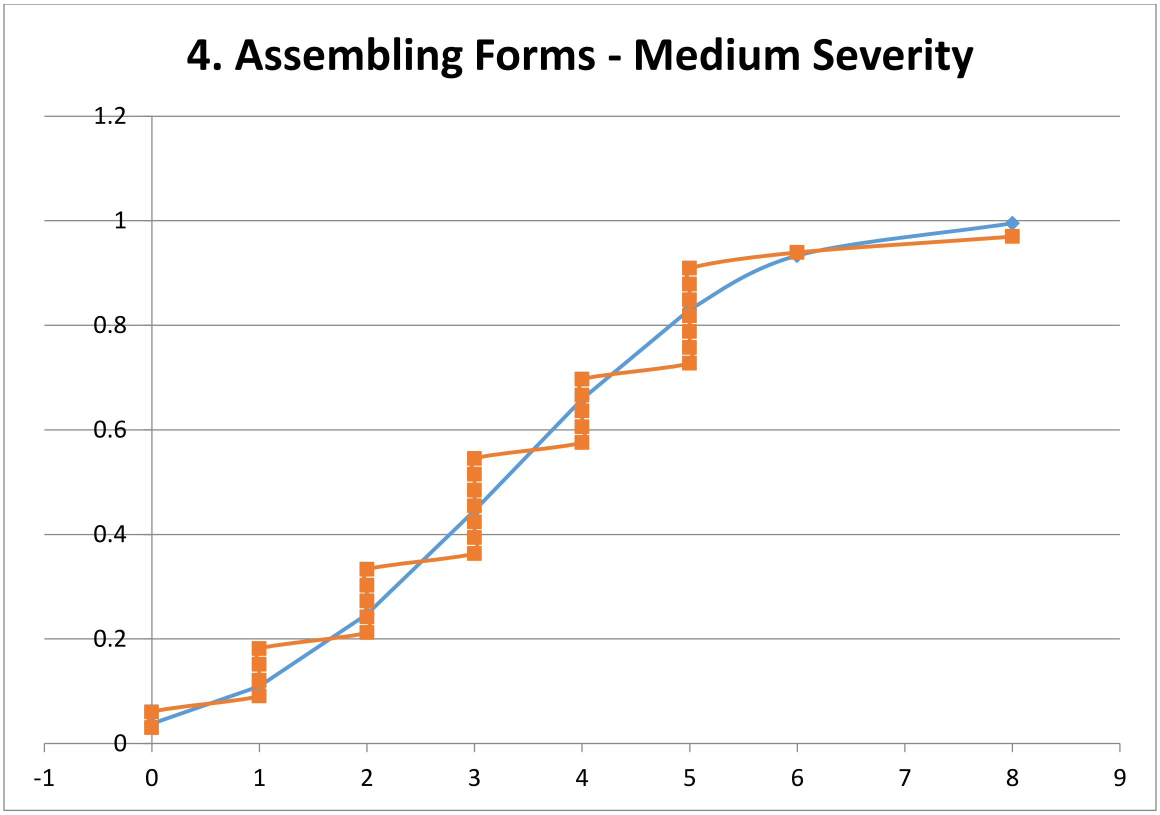


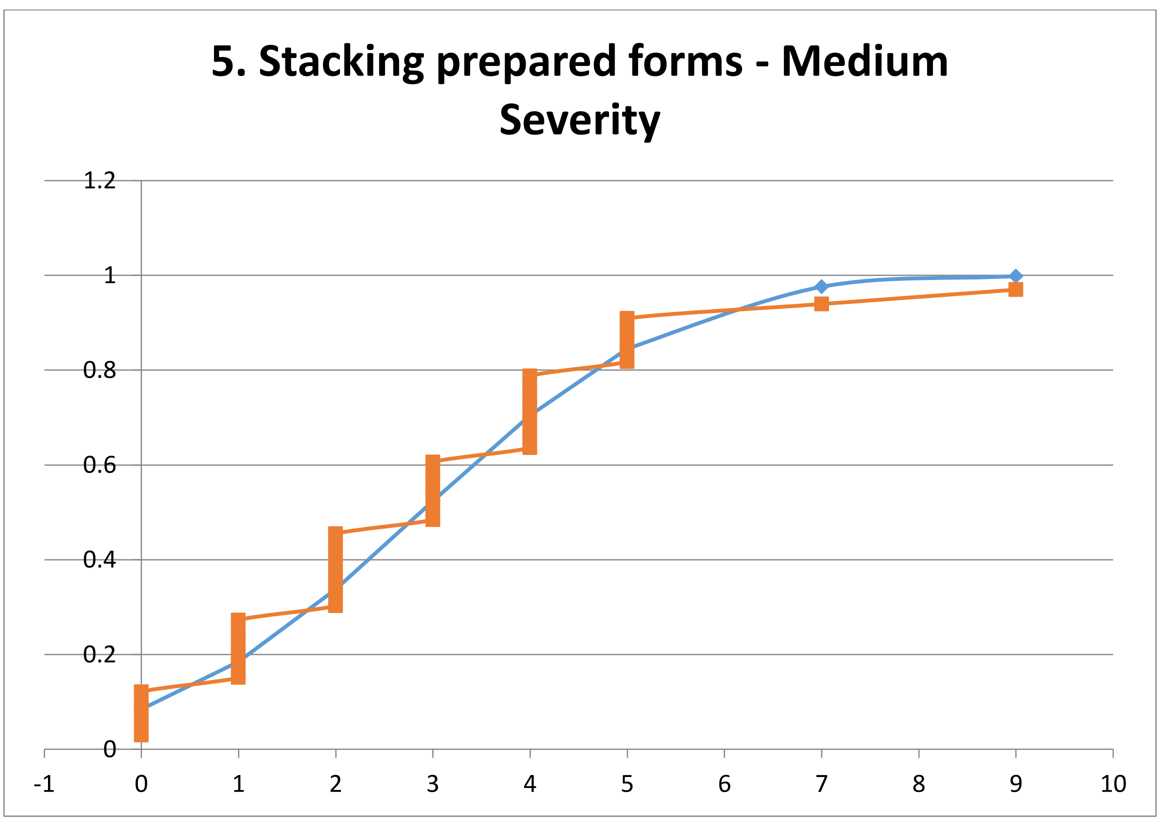
CDF Plots for Medium Severity: Normal distribution

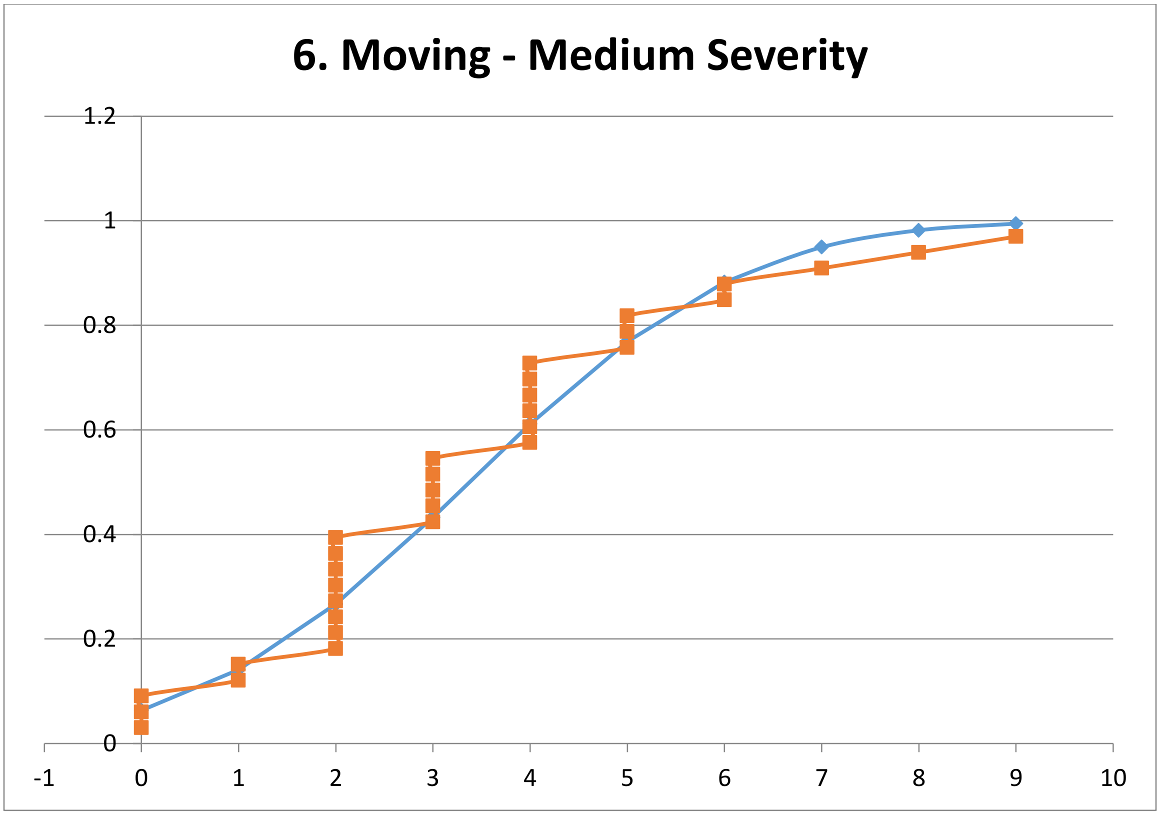


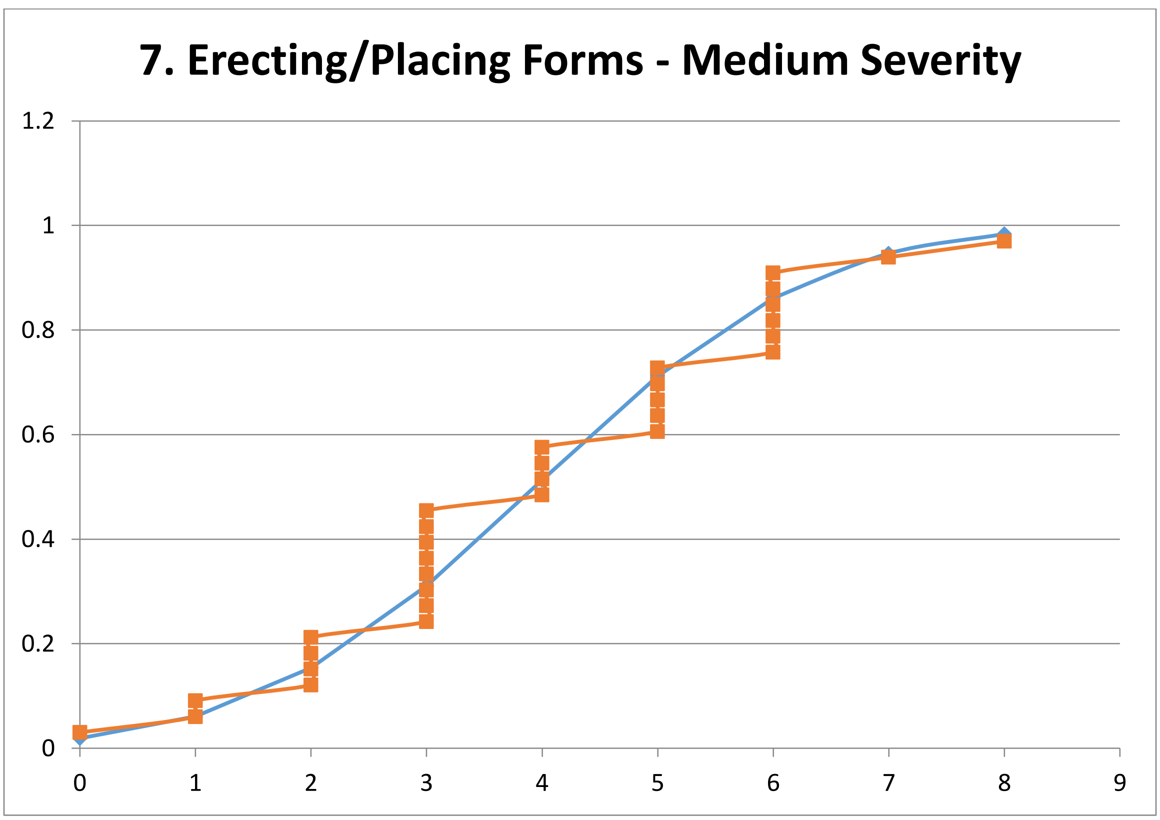

2. Preparation - Medium Severity
1.2
1
0.8
0.6
0.4
0.2
0
-1
0
1
2
3
4
5
6
7
8
9

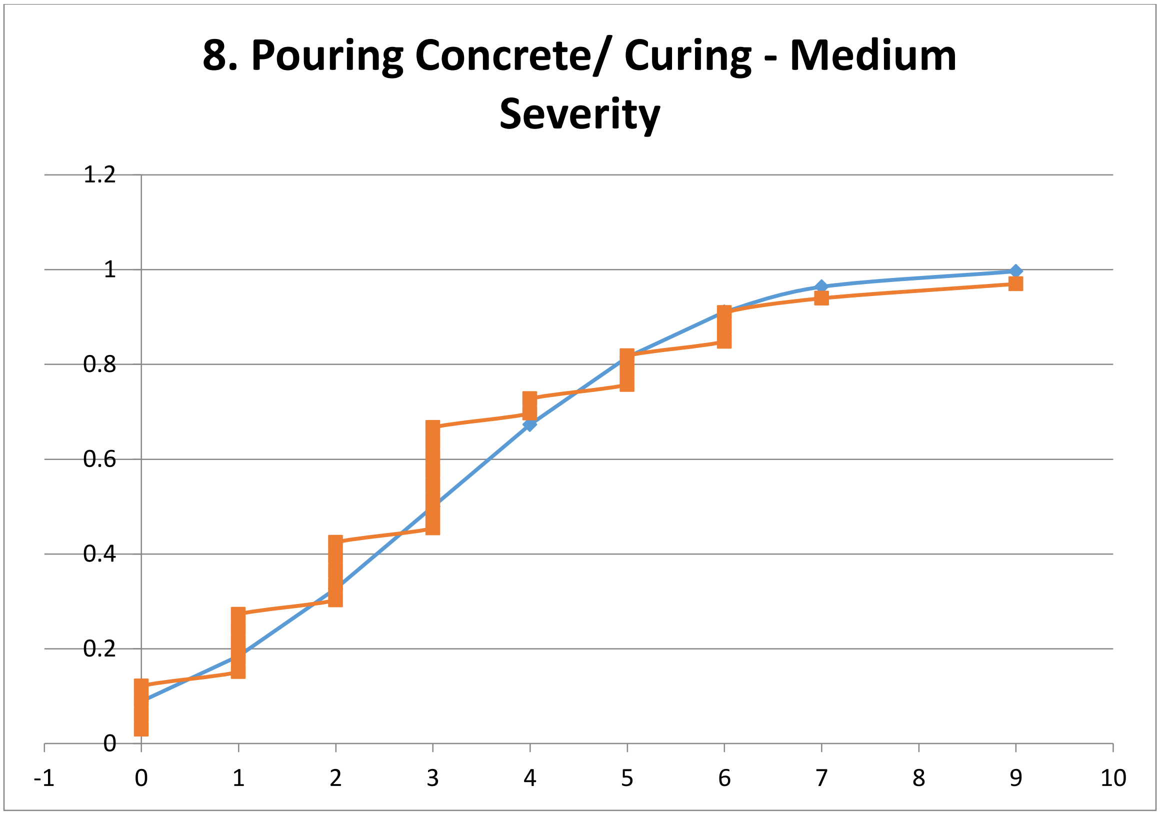

3. Moving (Optional) - Medium Severity
1.2
1
0.8
0.6
0.4
0.2
0
-1
0
1
2
3
4
5
6
7
8
9
10

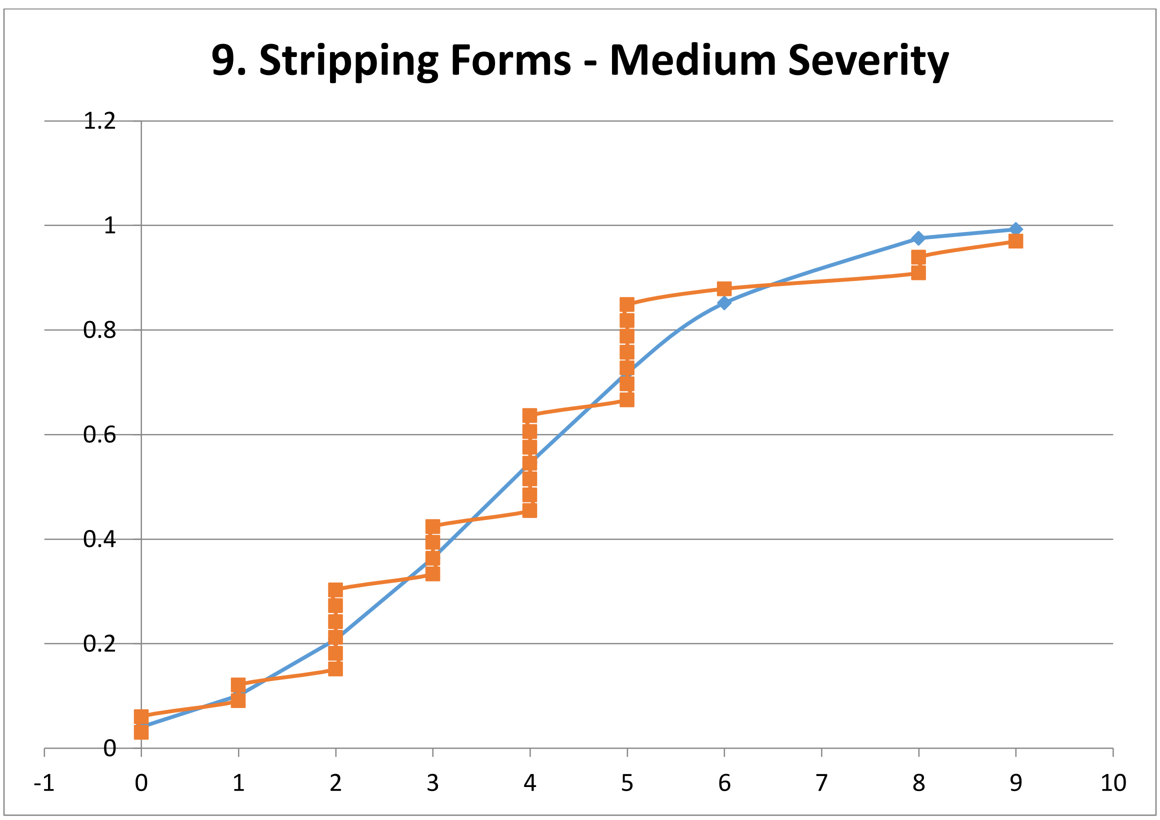

4. Assembling Forms - Medium Severity
1.2
1
0.8
0.6
0.4
0.2
0
-1
0
1
2
3
4
5
6
7
8
9

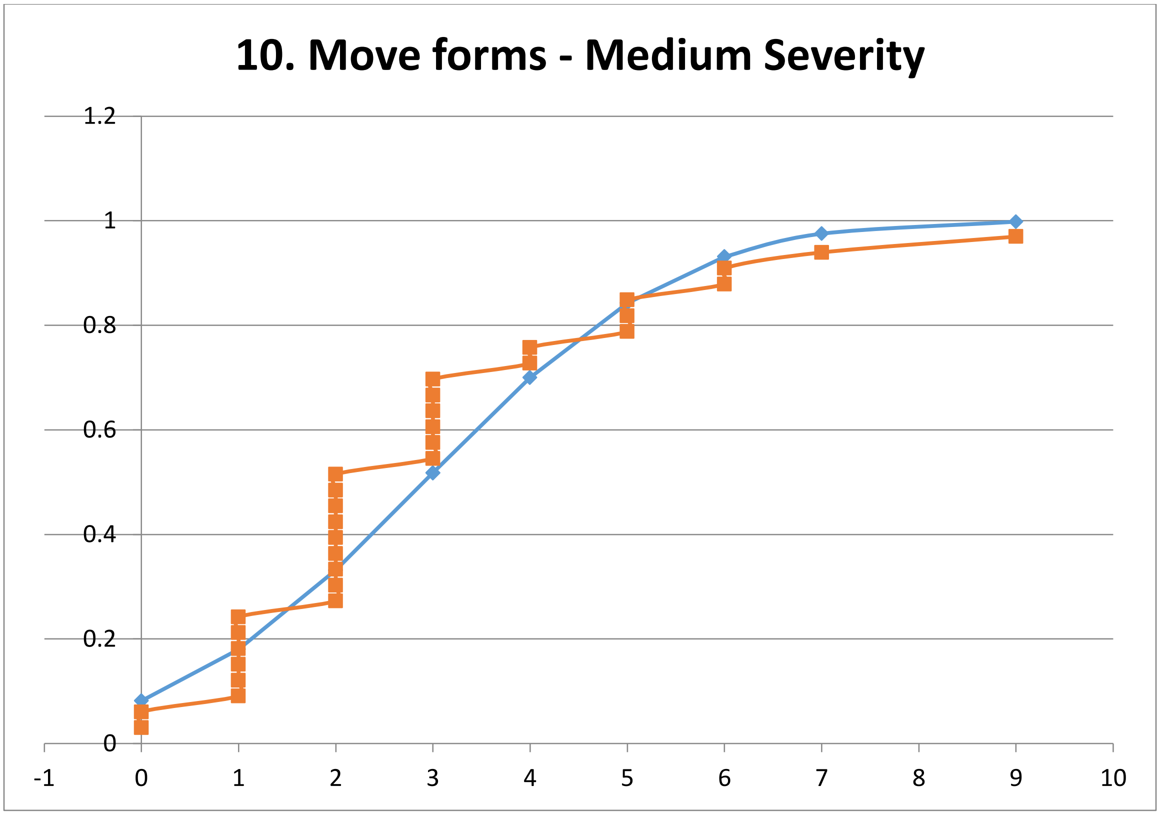

5. Stacking prepared forms - Medium Severity
1.2
1
0.8
0.6
0.4
0.2
0
-1
0
1
2
3
4
5
6
7
8
9
10

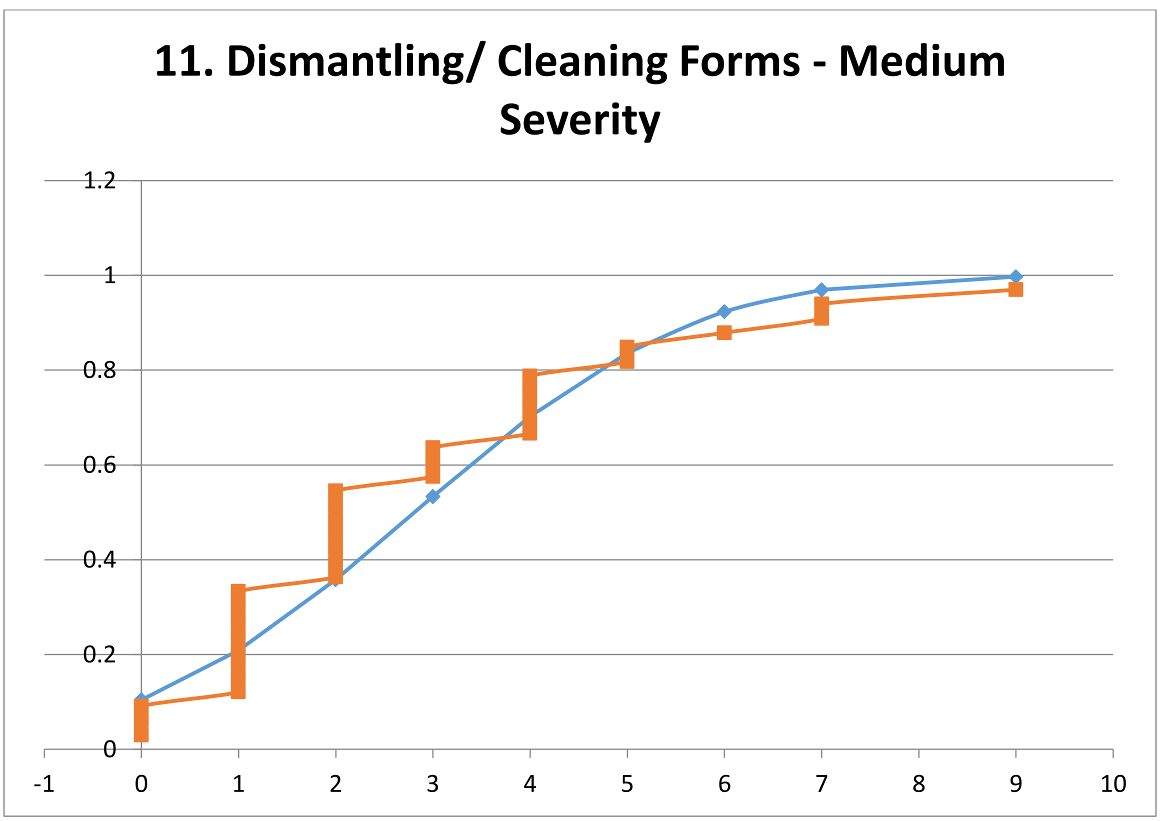

6. Moving - Medium Severity
1.2
1
0.8
0.6
0.4
0.2
0
-1
0
1
2
3
4
5
6
7
8
9
10

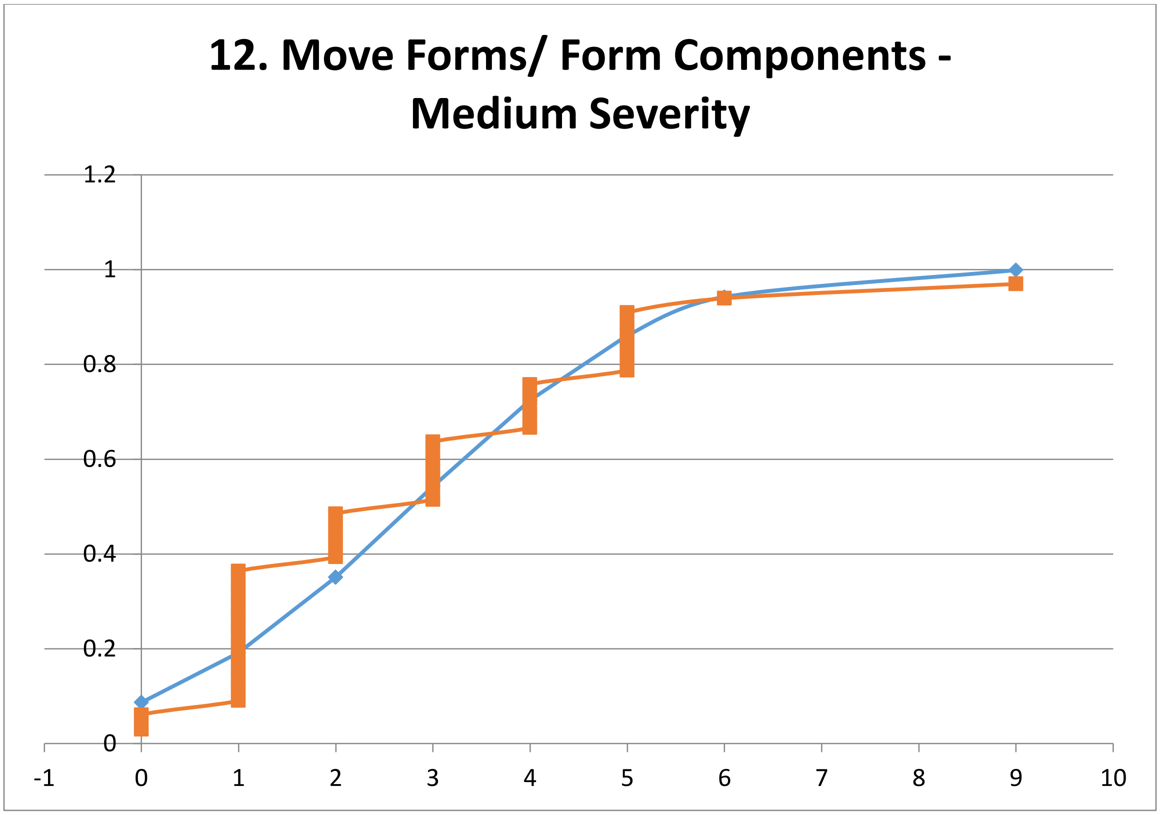

7. Erecting/Placing Forms - Medium Severity
1.2
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5
6
7
8
9

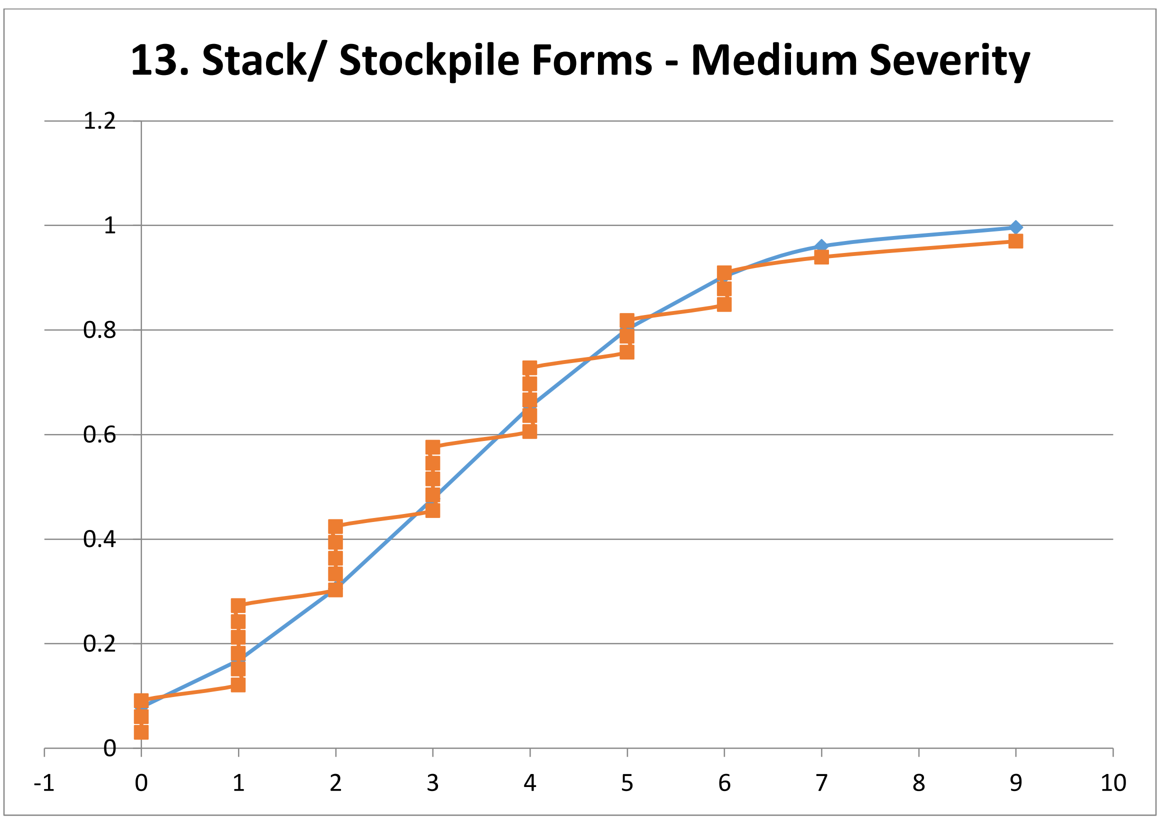

8. Pouring Concrete/ Curing - Medium Severity
1.2
1
0.8
0.6
0.4
0.2
0
-1
0
1
2
3
4
5
6
7
8
9
10


9. Stripping Forms - Medium Severity
1.2
1
0.8
0.6
0.4
0.2
0
-1
0
1
2
3
4
5
6
7
8
9
10

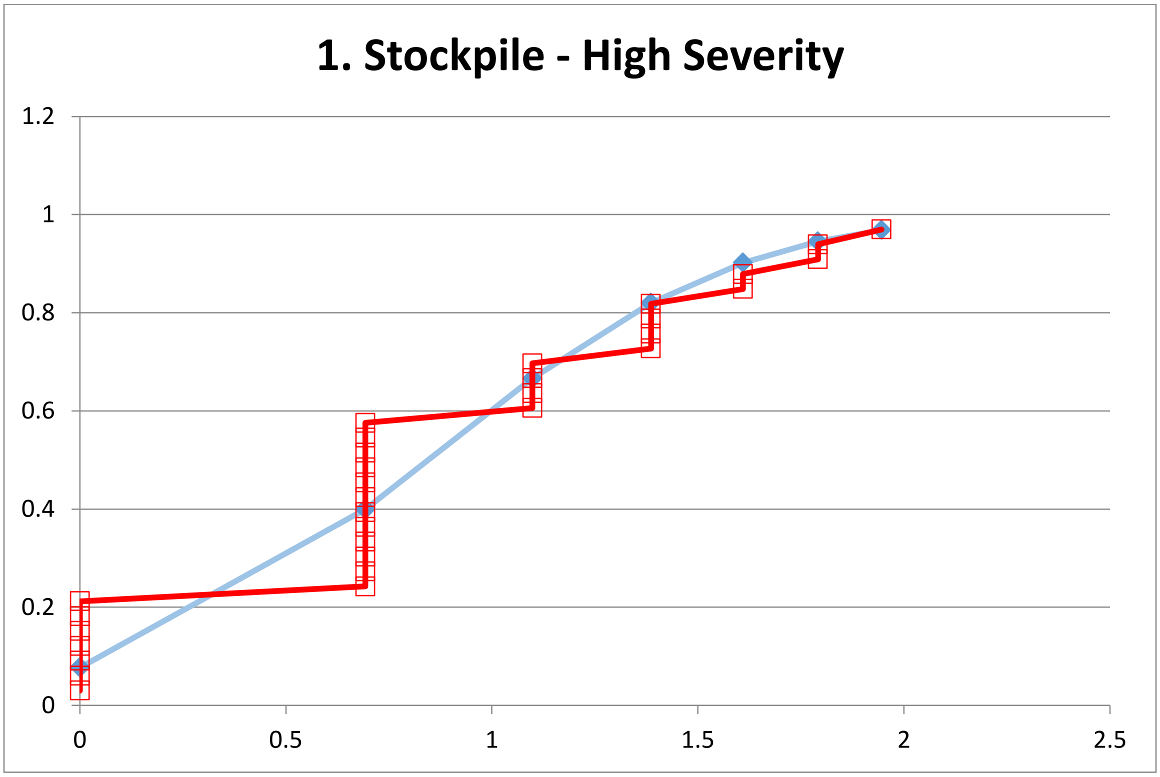

10. Move forms - Medium Severity
1.2
1
0.8
0.6
0.4
0.2
0
-1
0
1
2
3
4
5
6
7
8
9
10

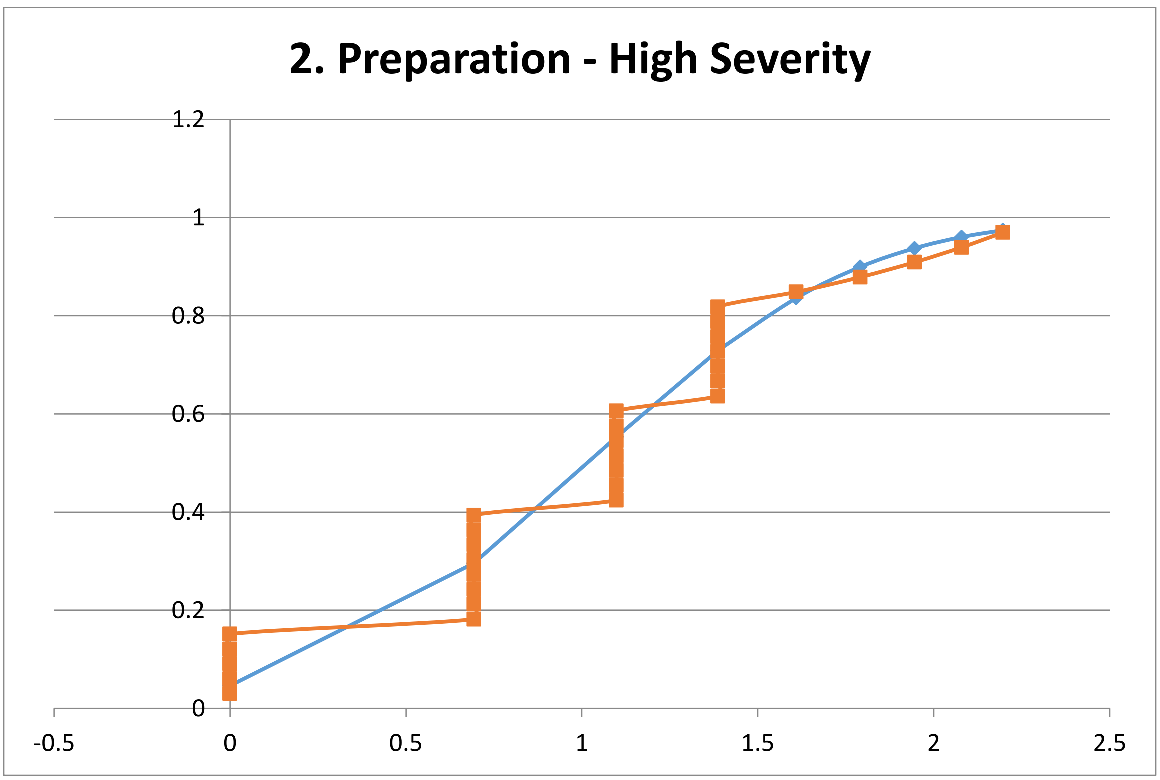

11. Dismantling/ Cleaning Forms - Medium Severity
1.2
1
0.8
0.6
0.4
0.2
0
-1
0
1
2
3
4
5
6
7
8
9
10

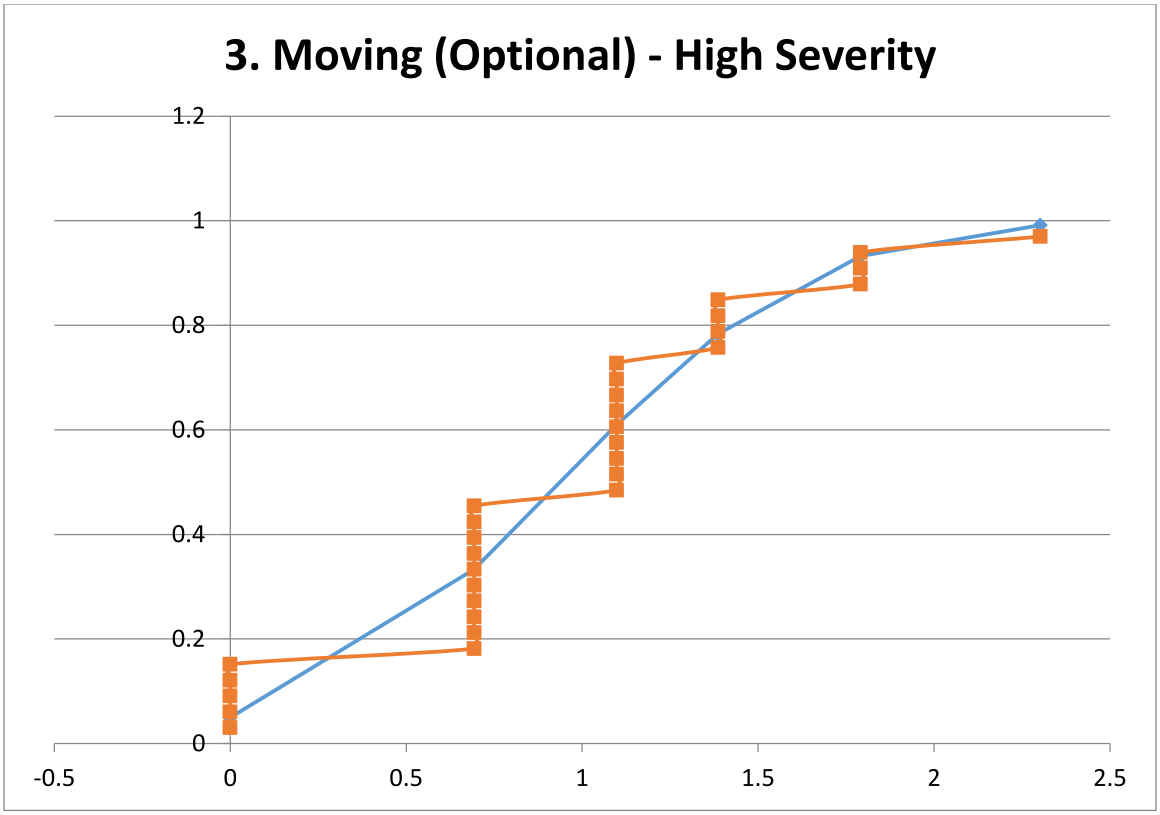

12. Move Forms/ Form Components - Medium Severity
1.2
1
0.8
0.6
0.4
0.2
0
-1
0
1
2
3
4
5
6
7
8
9
10

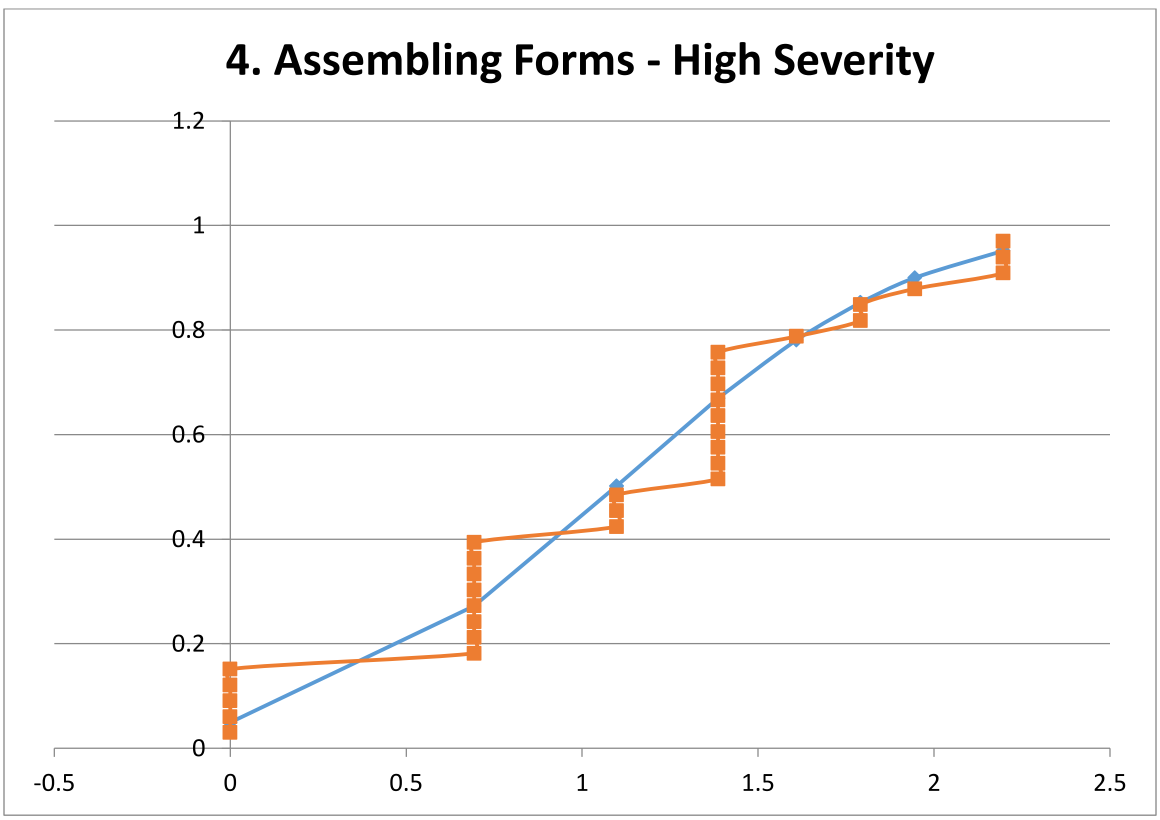

13. Stack/ Stockpile Forms - Medium Severity
1.2
1
0.8
0.6
0.4
0.2
0
-1
0
1
2
3
4
5
6
7
8
9
10

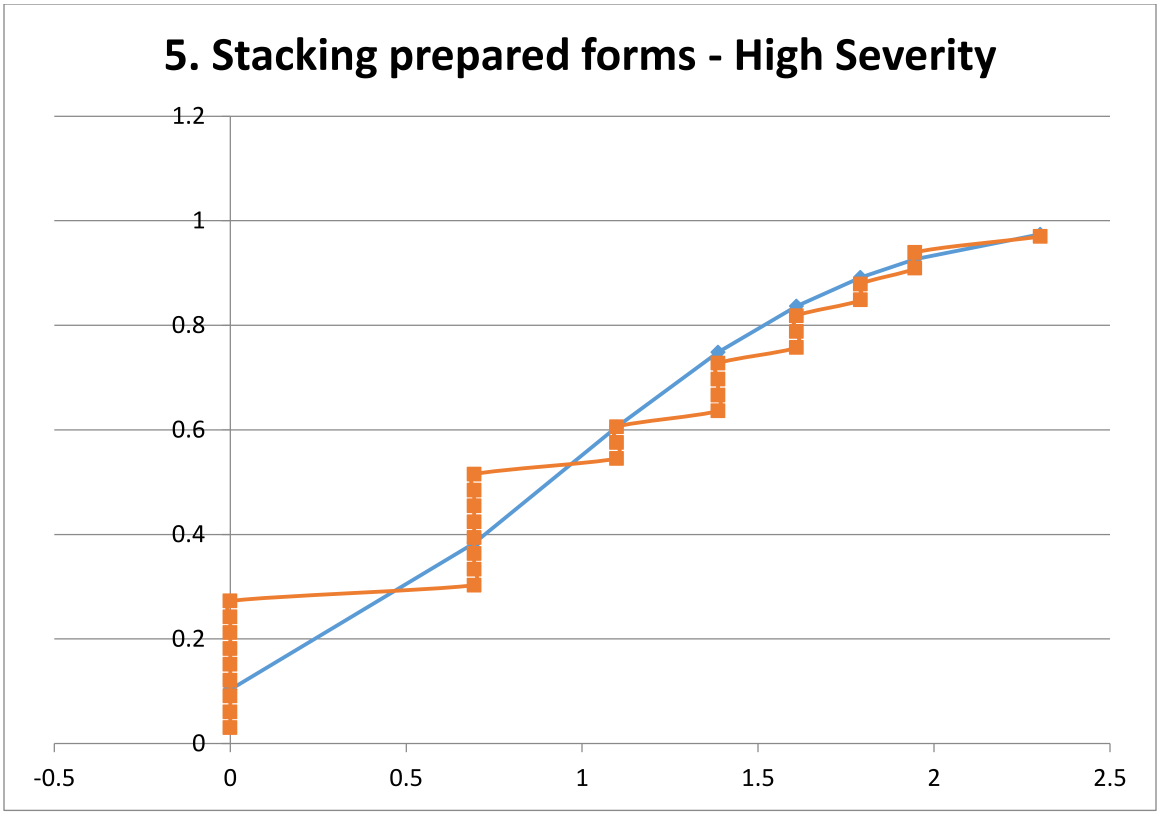
CDF Plots for High Severity: Lognormal distribution

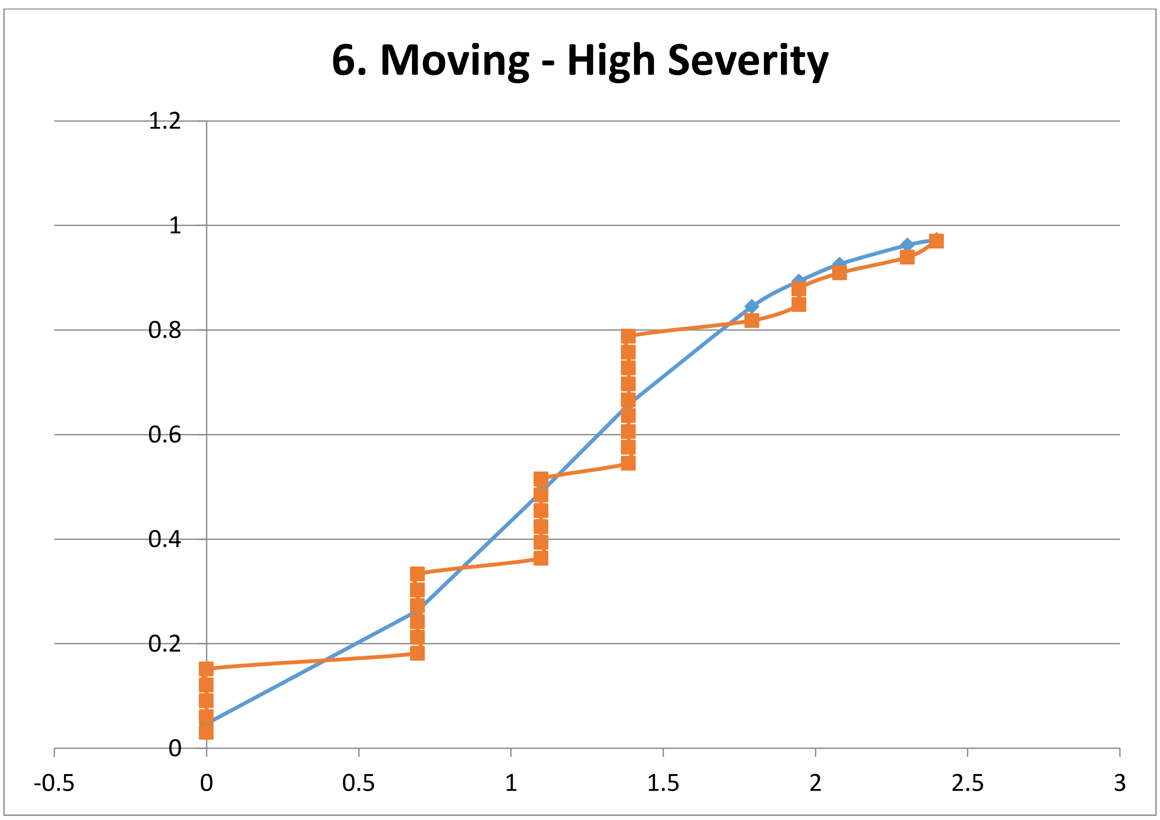


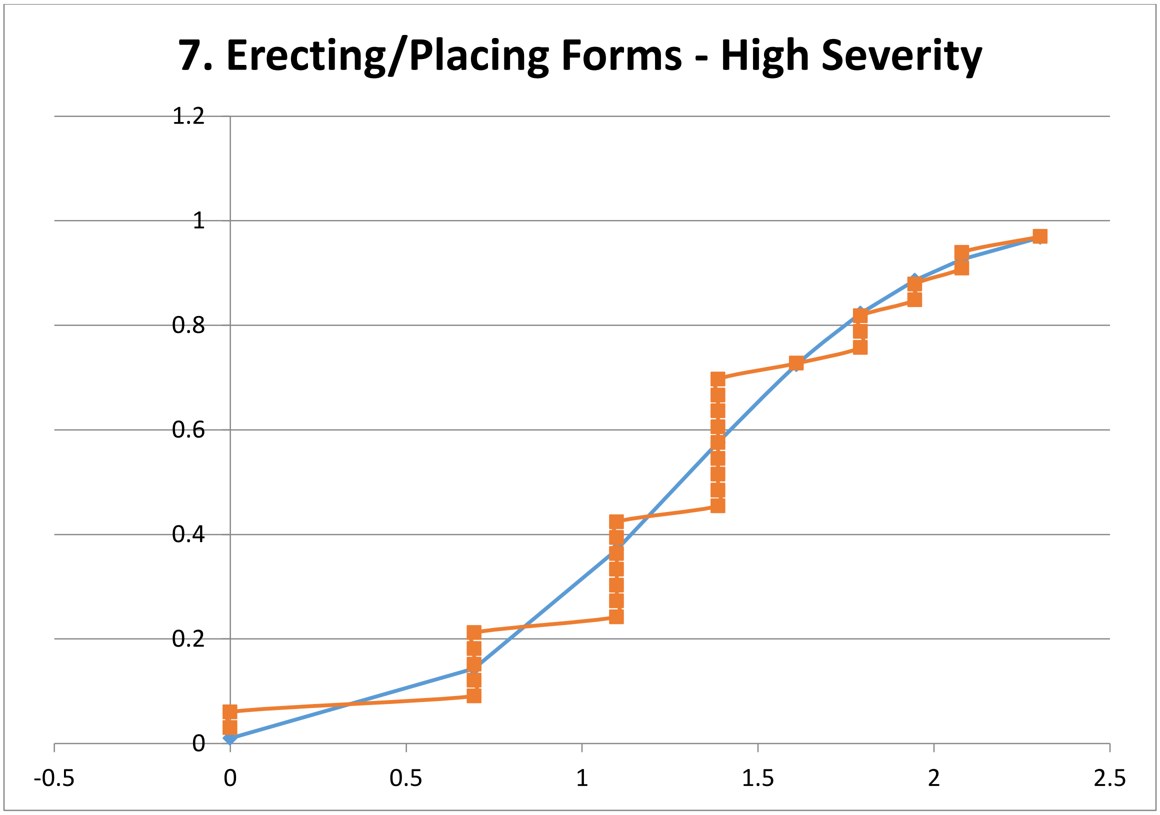


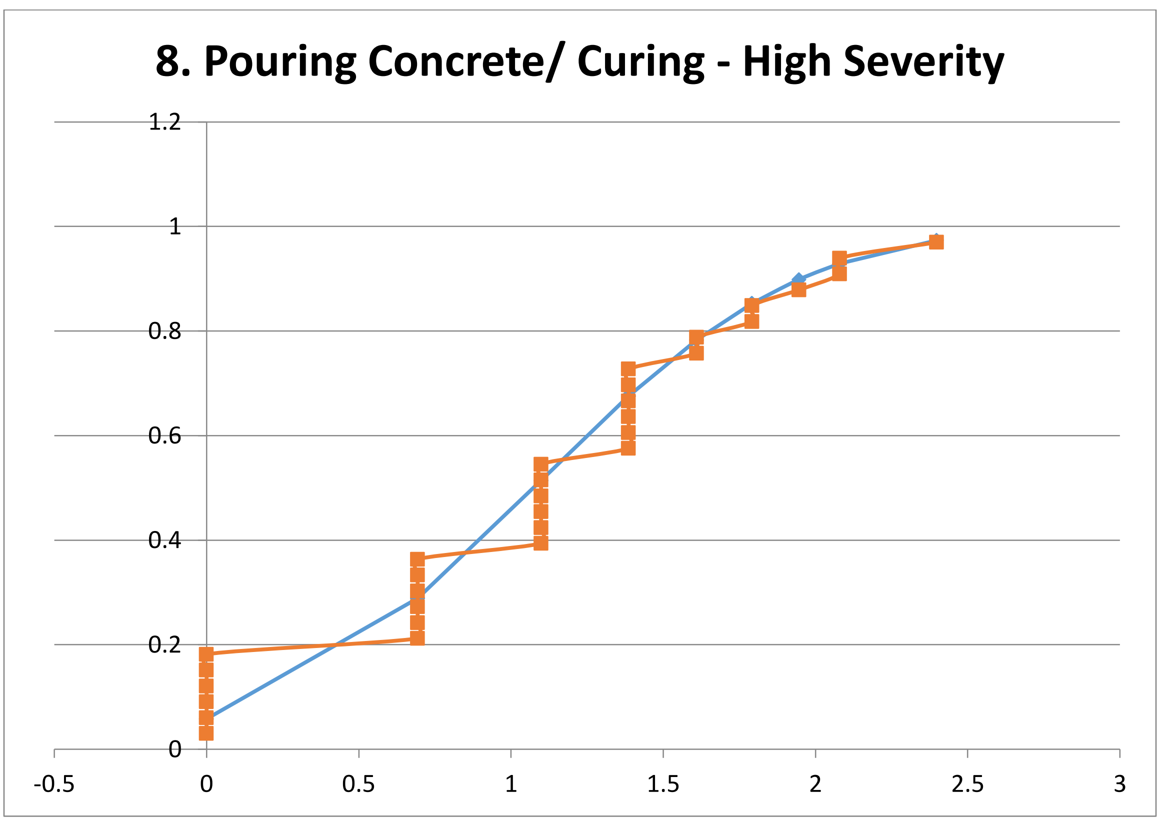

3. Moving (Optional) - High Severity
1.2
1
0.8
0.6
0.4
0.2
0
-0.5
0
0.5
1
1.5
2
2.5

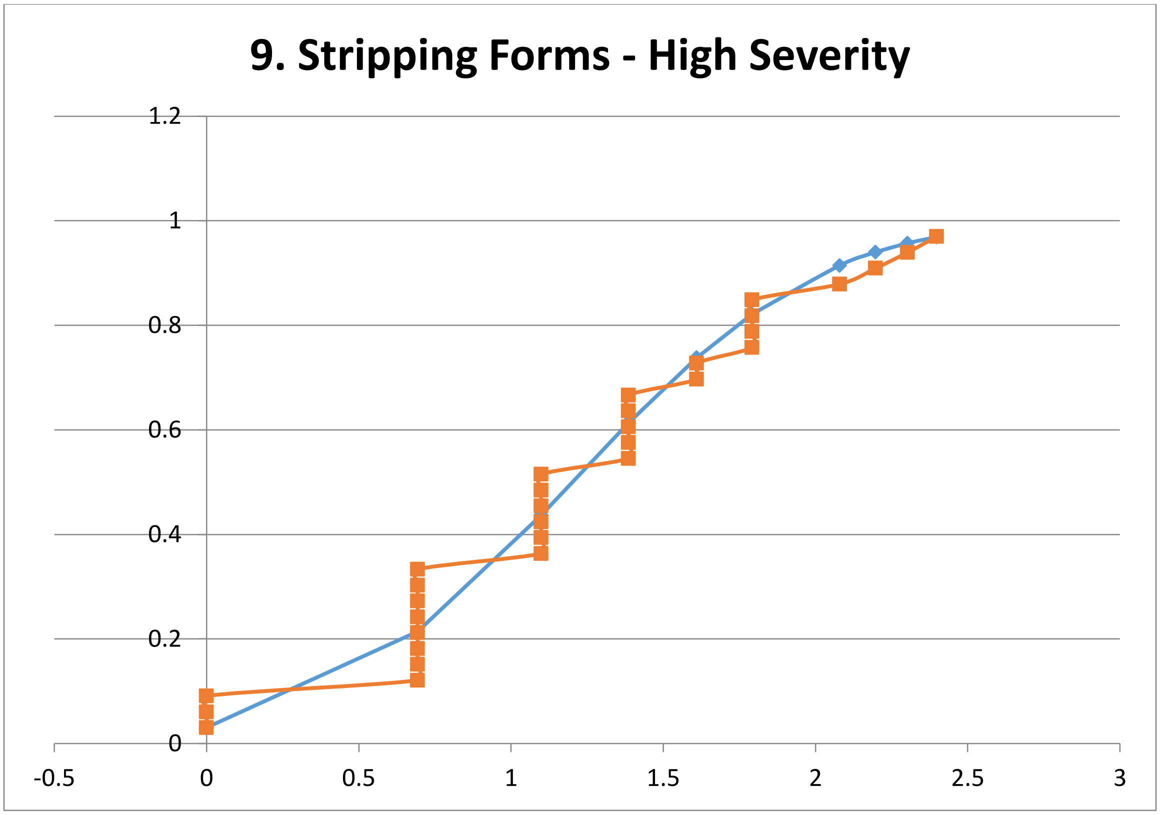

4. Assembling Forms - High Severity
1.2
1
0.8
0.6
0.4
0.2
0
-0.5
0
0.5
1
1.5
2
2.5

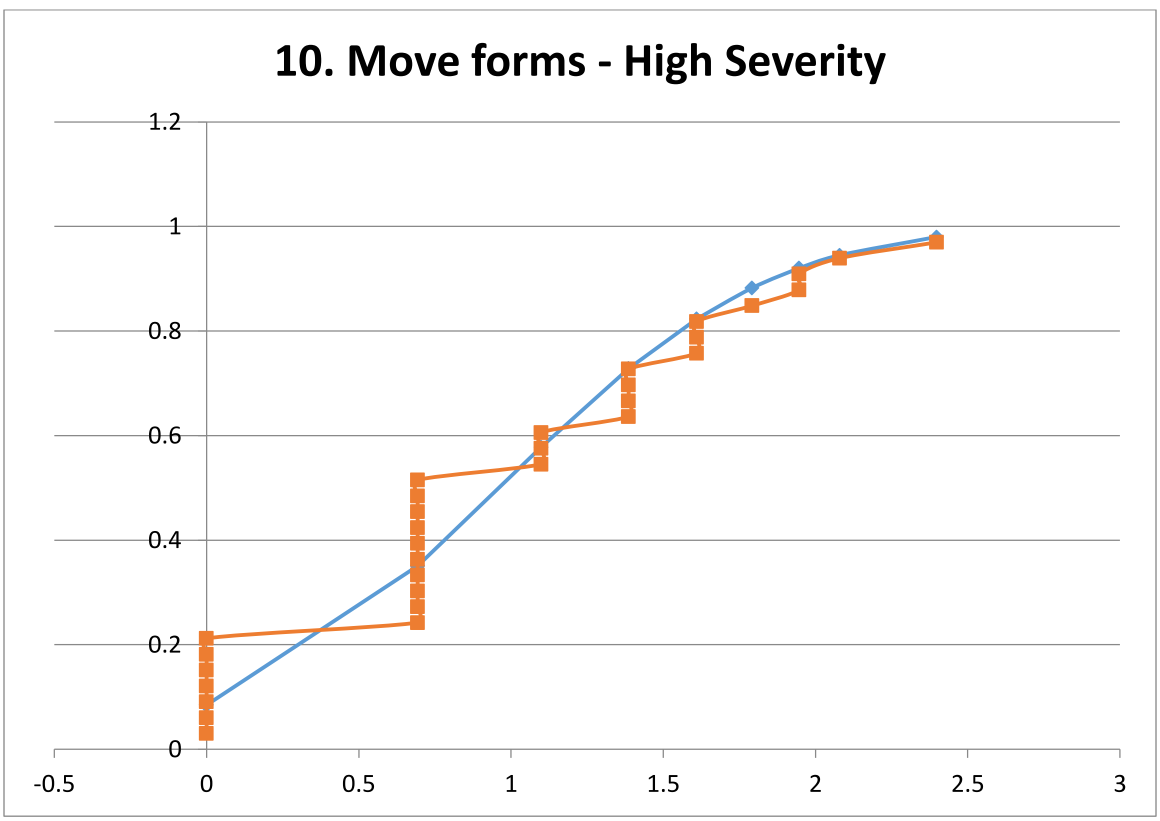

5. Stacking prepared forms - High Severity
1.2
1
0.8
0.6
0.4
0.2
0
-0.5
0
0.5
1
1.5
2
2.5

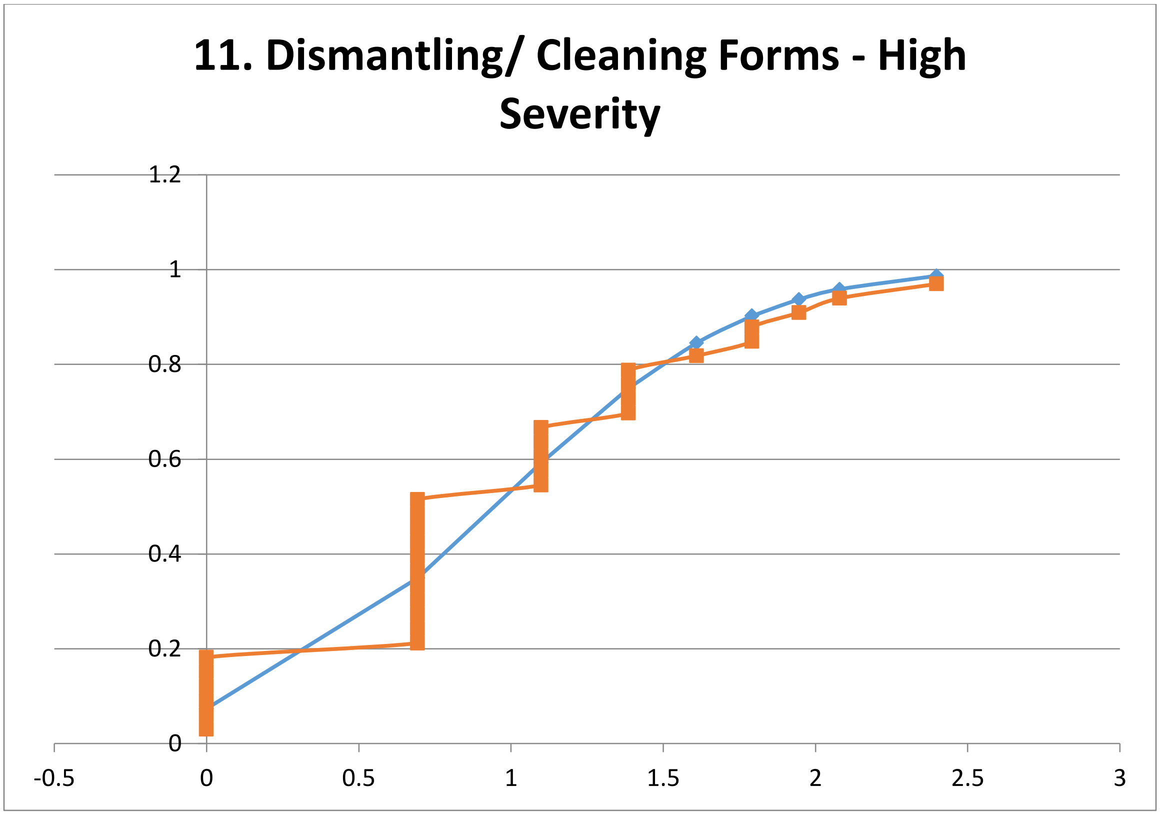

6. Moving - High Severity
1.2
1
0.8
0.6
0.4
0.2
0
-0.5
0
0.5
1
1.5
2
2.5
3

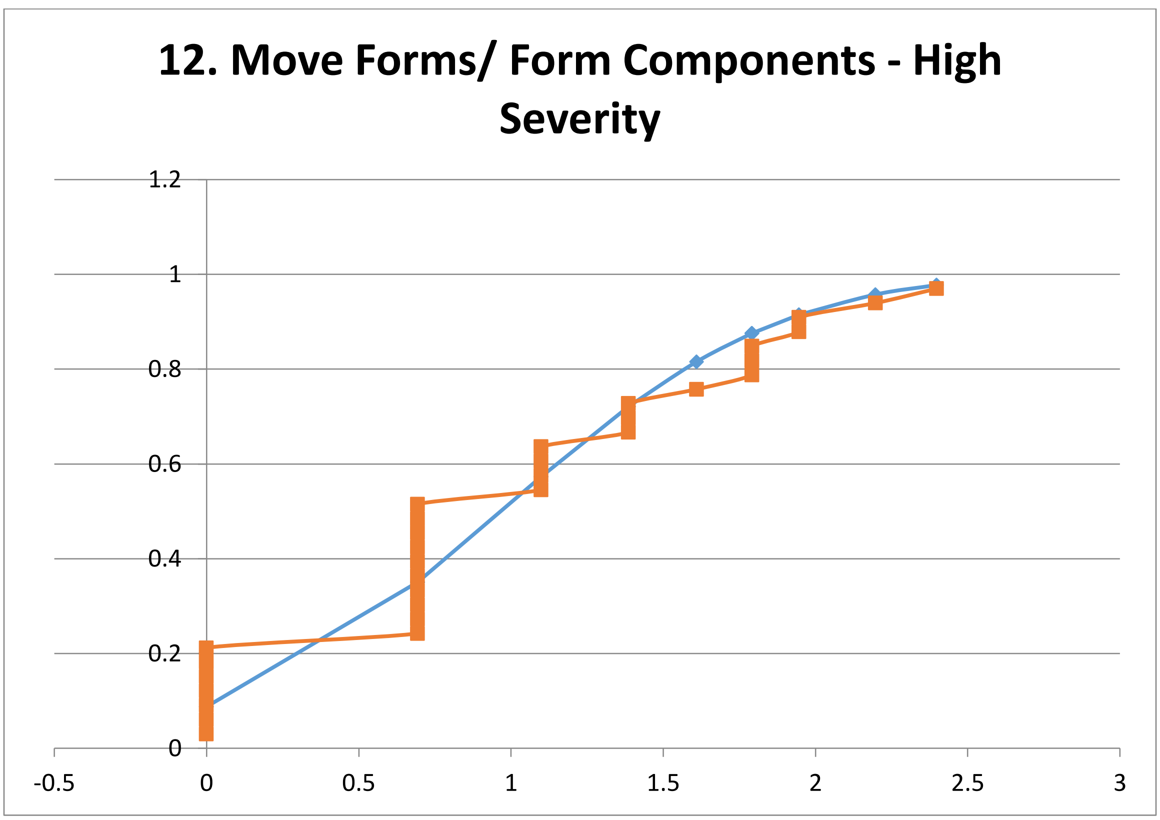

7. Erecting/Placing Forms - High Severity
1.2
1
0.8
0.6
0.4
0.2
0
-0.5
0
0.5
1
1.5
2
2.5

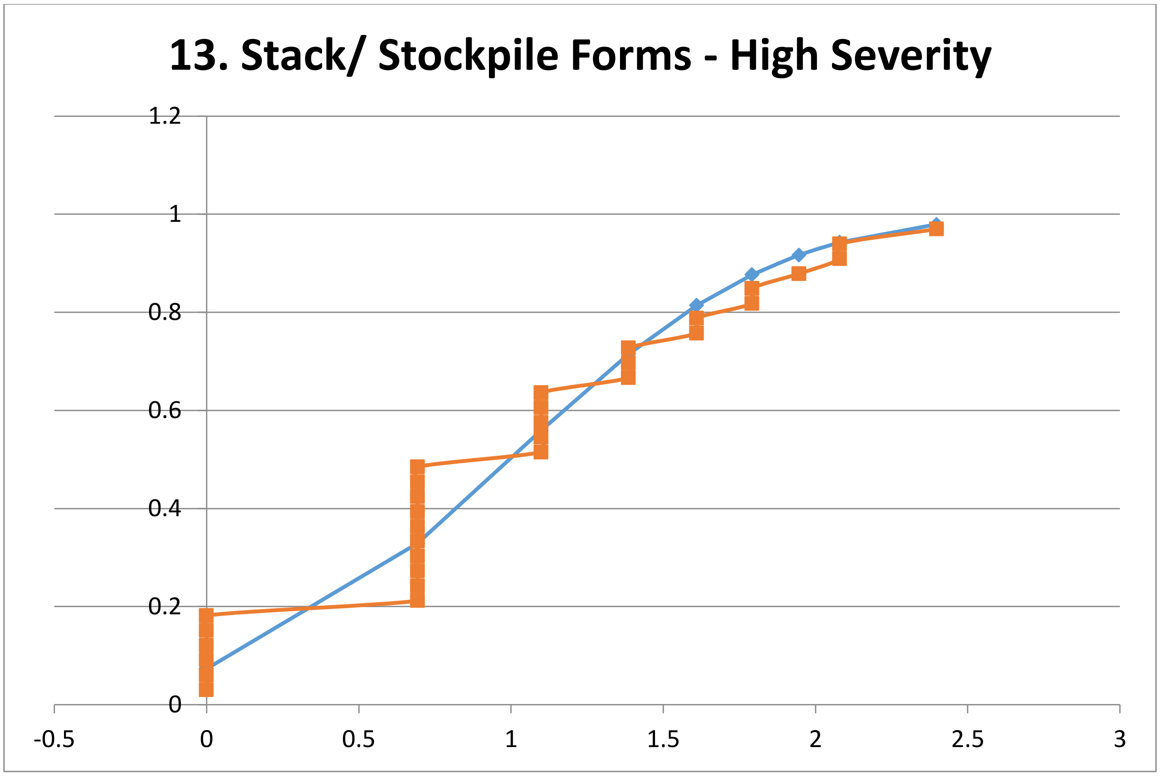

8. Pouring Concrete/ Curing - High Severity
1.2
1
0.8
0.6
0.4
0.2
0
-0.5
0
0.5
1
1.5
2
2.5
3


9. Stripping Forms - High Severity
1.2
1
0.8
0.6
0.4
0.2
0
-0.5
0
0.5
1
1.5
2
2.5
3

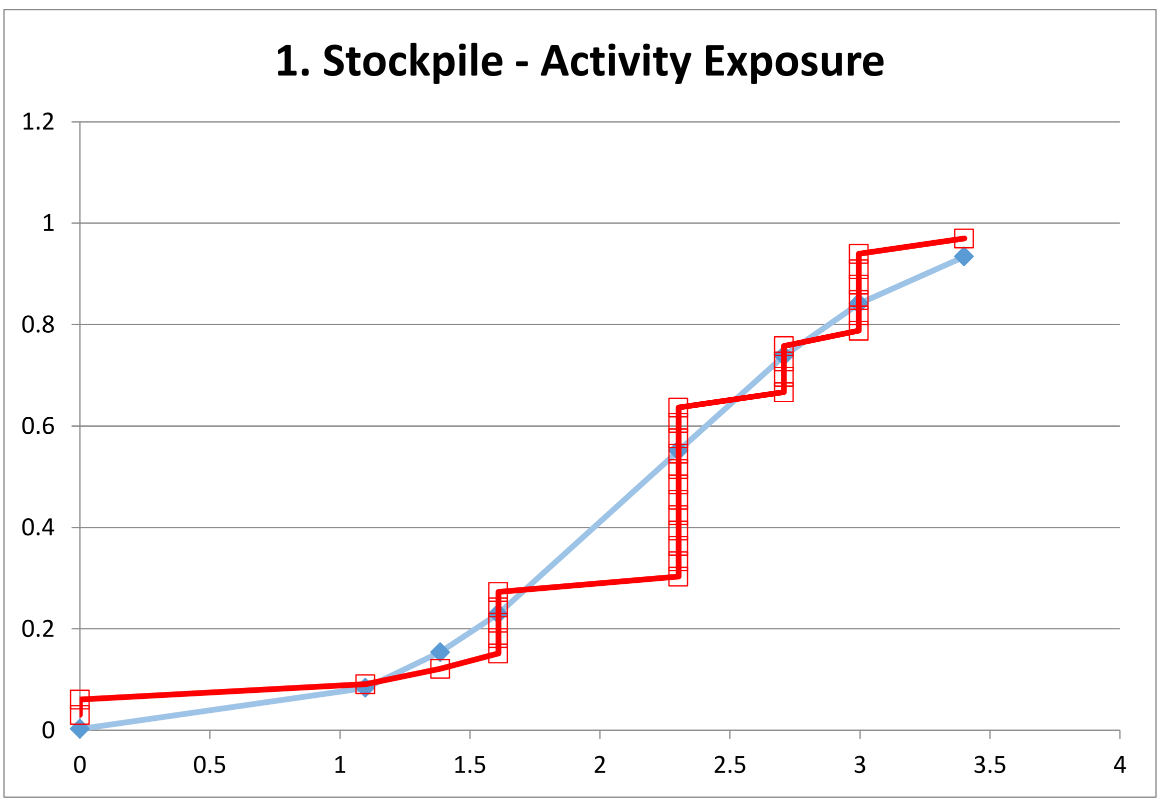

10. Move forms - High Severity
1.2
1
0.8
0.6
0.4
0.2
0
-0.5
0
0.5
1
1.5
2
2.5
3

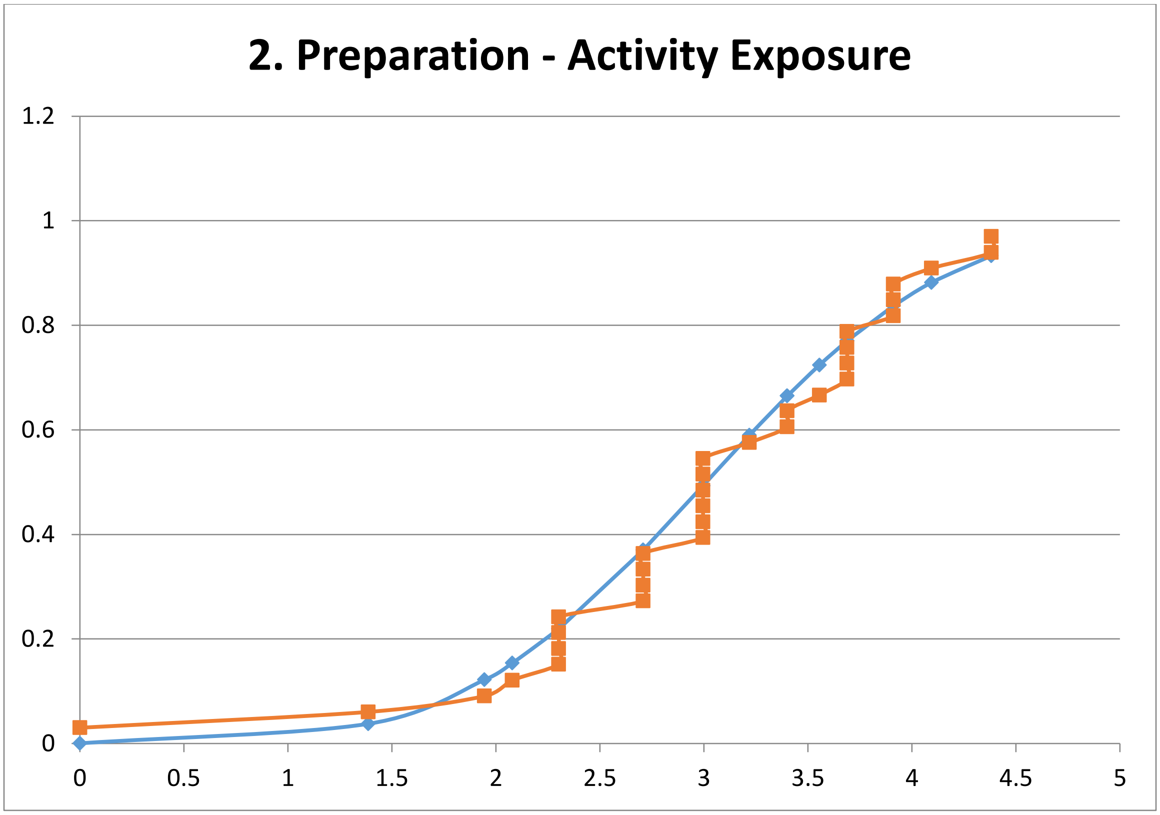

11. Dismantling/ Cleaning Forms - High Severity
1.2
1
0.8
0.6
0.4
0.2
0
-0.5
0
0.5
1
1.5
2
2.5
3

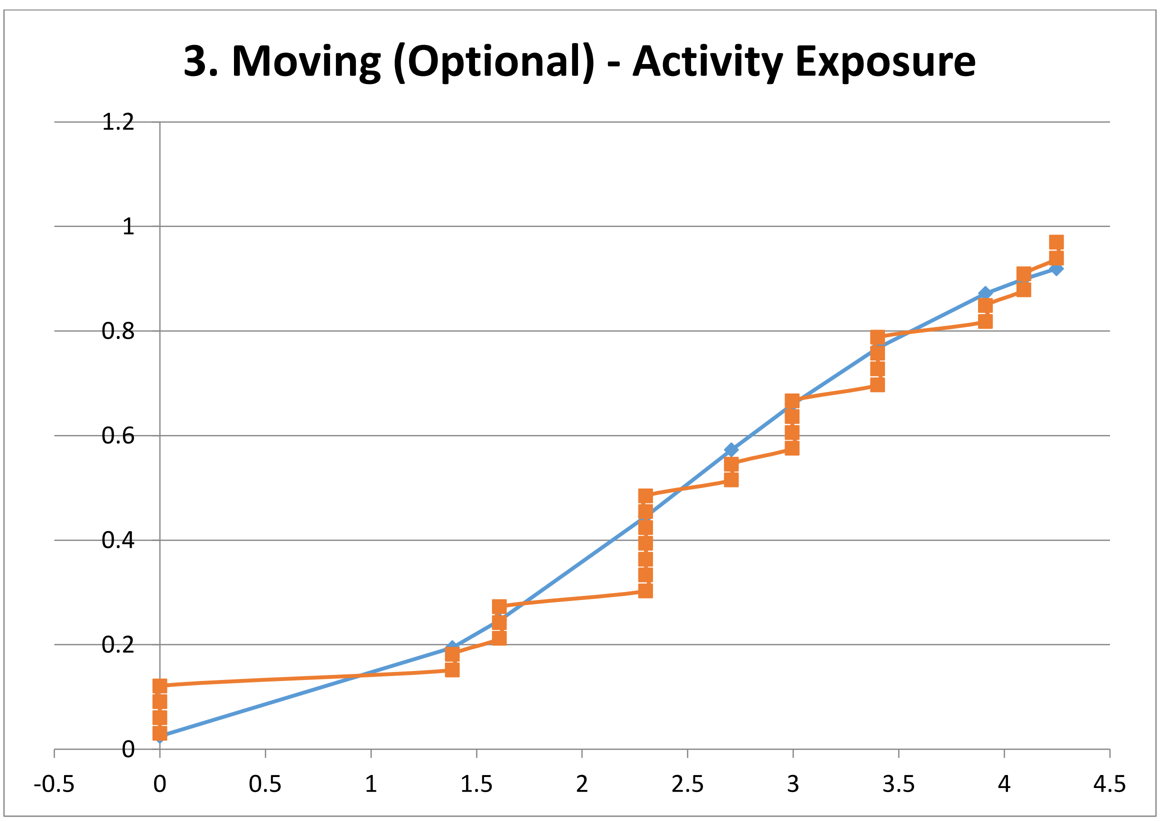

12. Move Forms/ Form Components - High Severity
1.2
1
0.8
0.6
0.4
0.2
0
-0.5
0
0.5
1
1.5
2
2.5
3

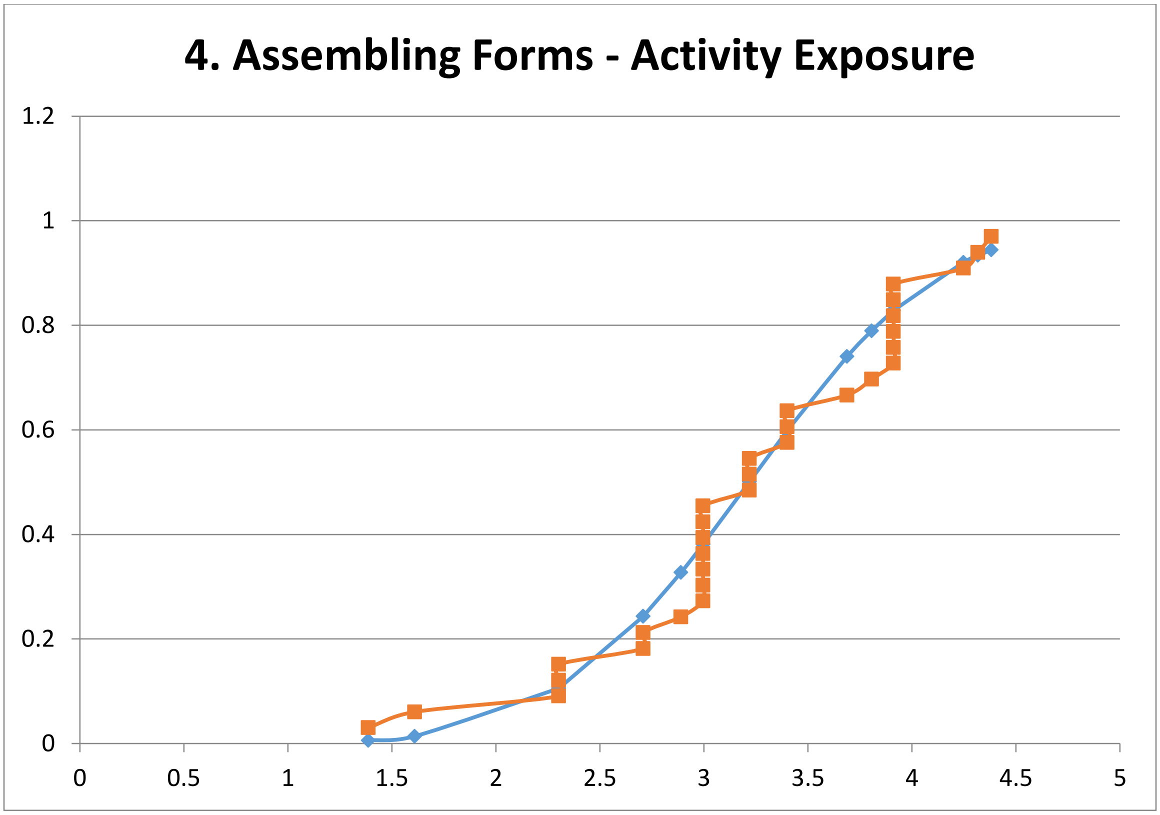


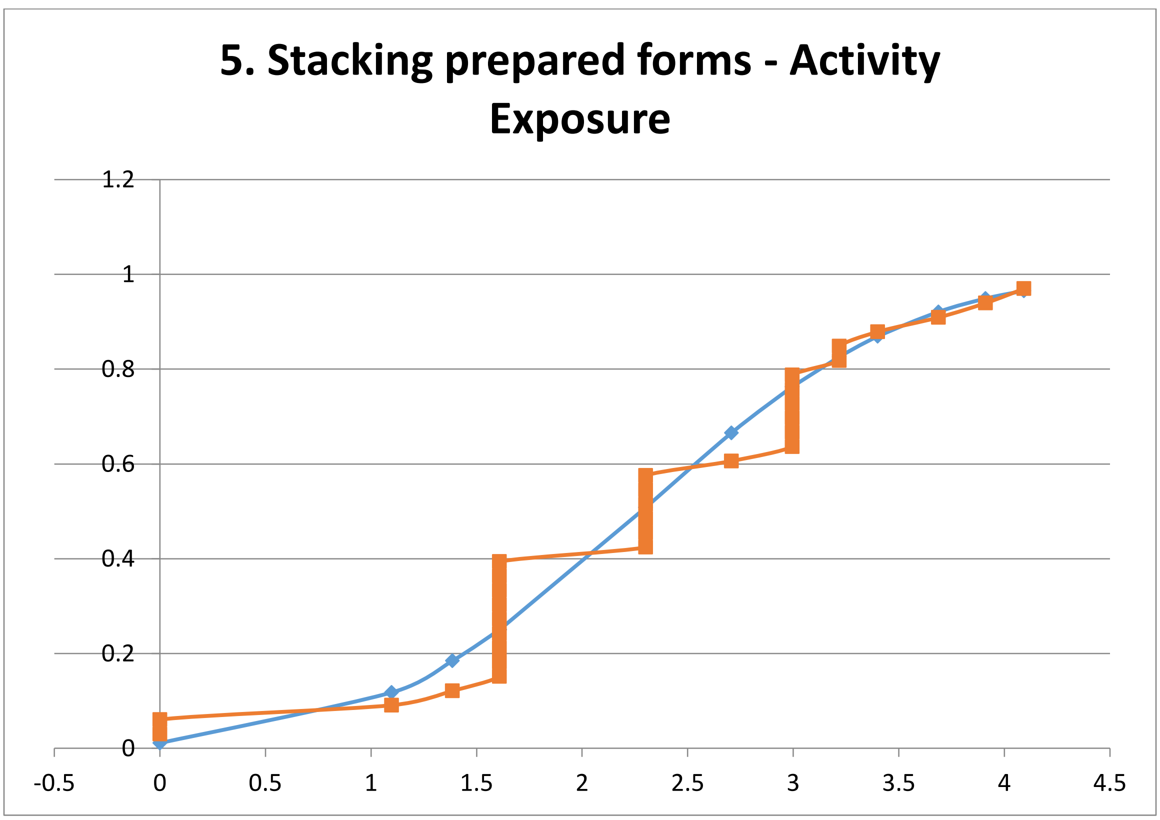
CDF Plots for Activity Exposure: Lognormal distribution

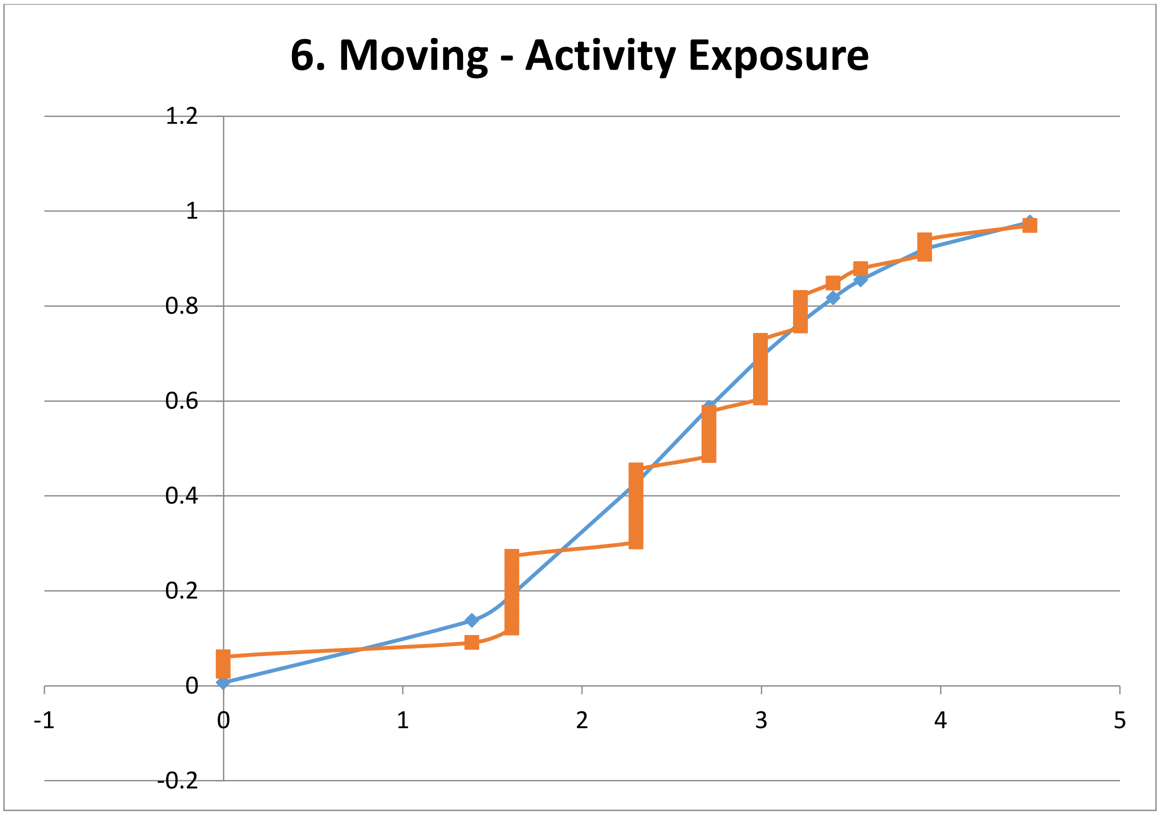


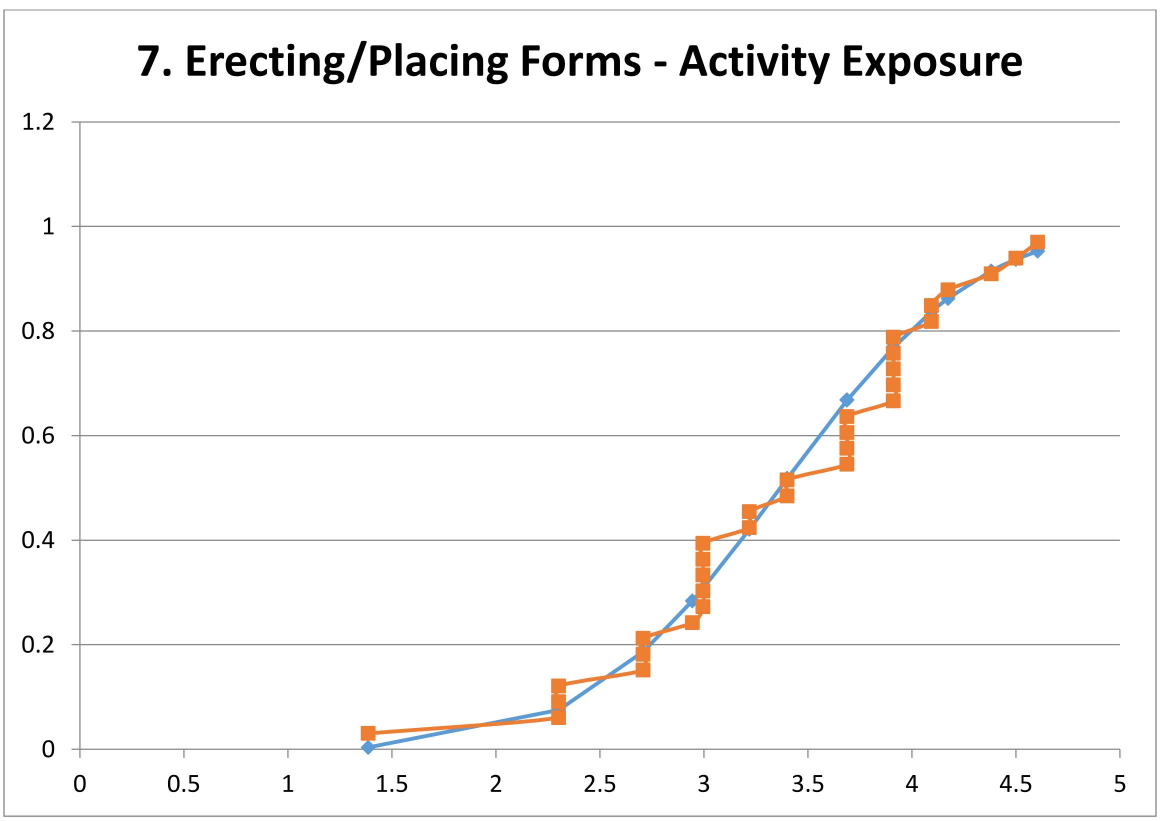

2. Preparation - Activity Exposure
1.2
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

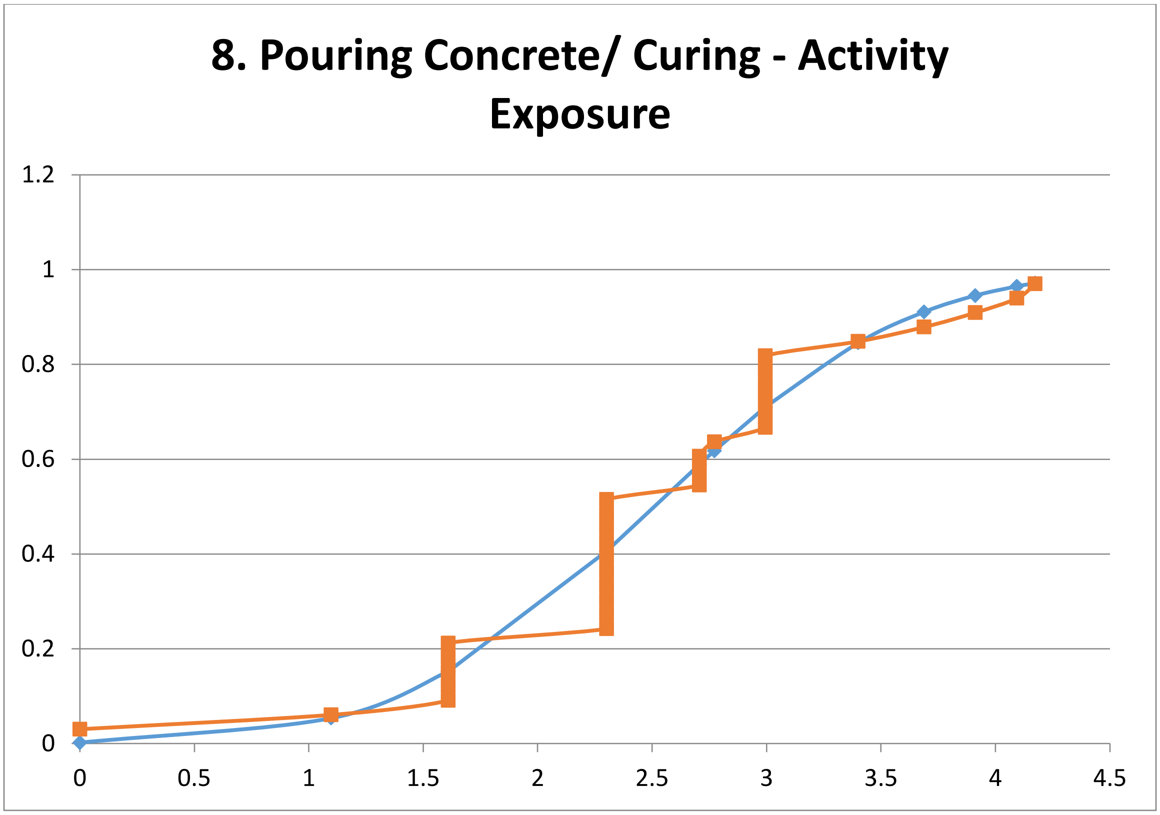

3. Moving (Optional) - Activity Exposure
1.2
1
0.8
0.6
0.4
0.2
0
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5

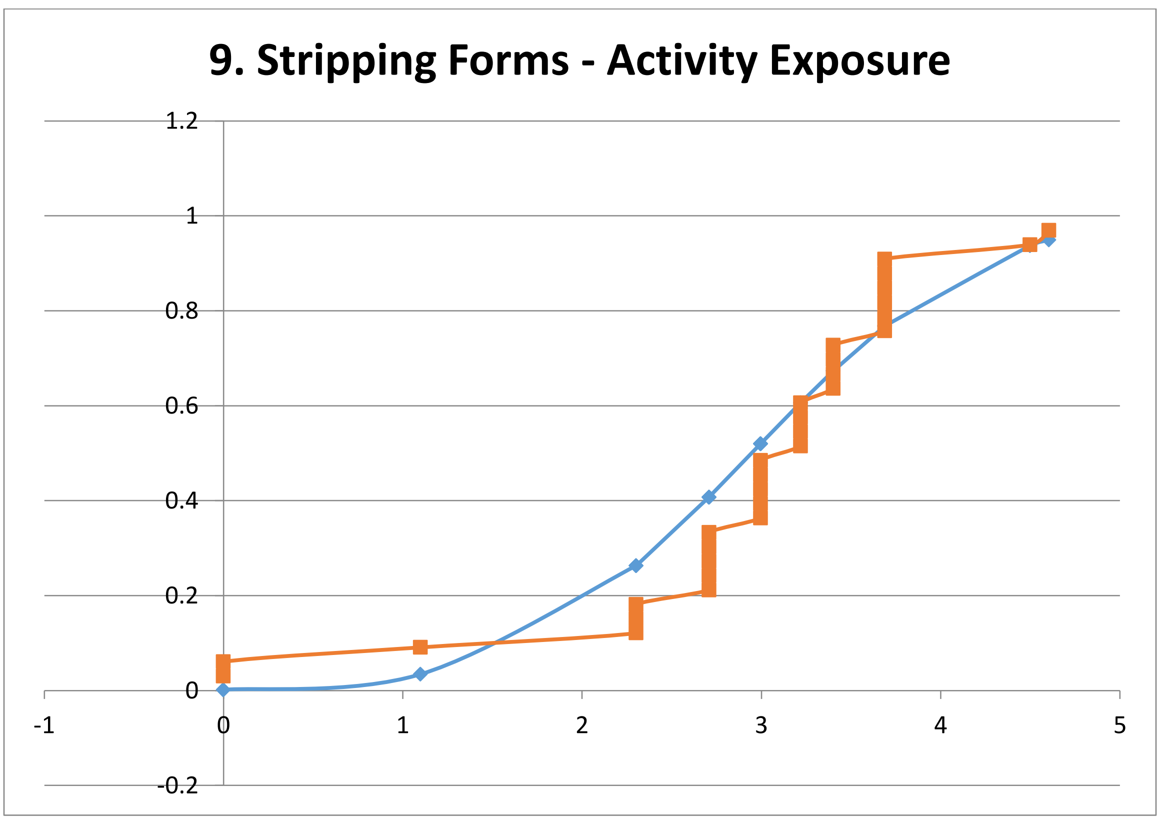

4. Assembling Forms - Activity Exposure
1.2
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

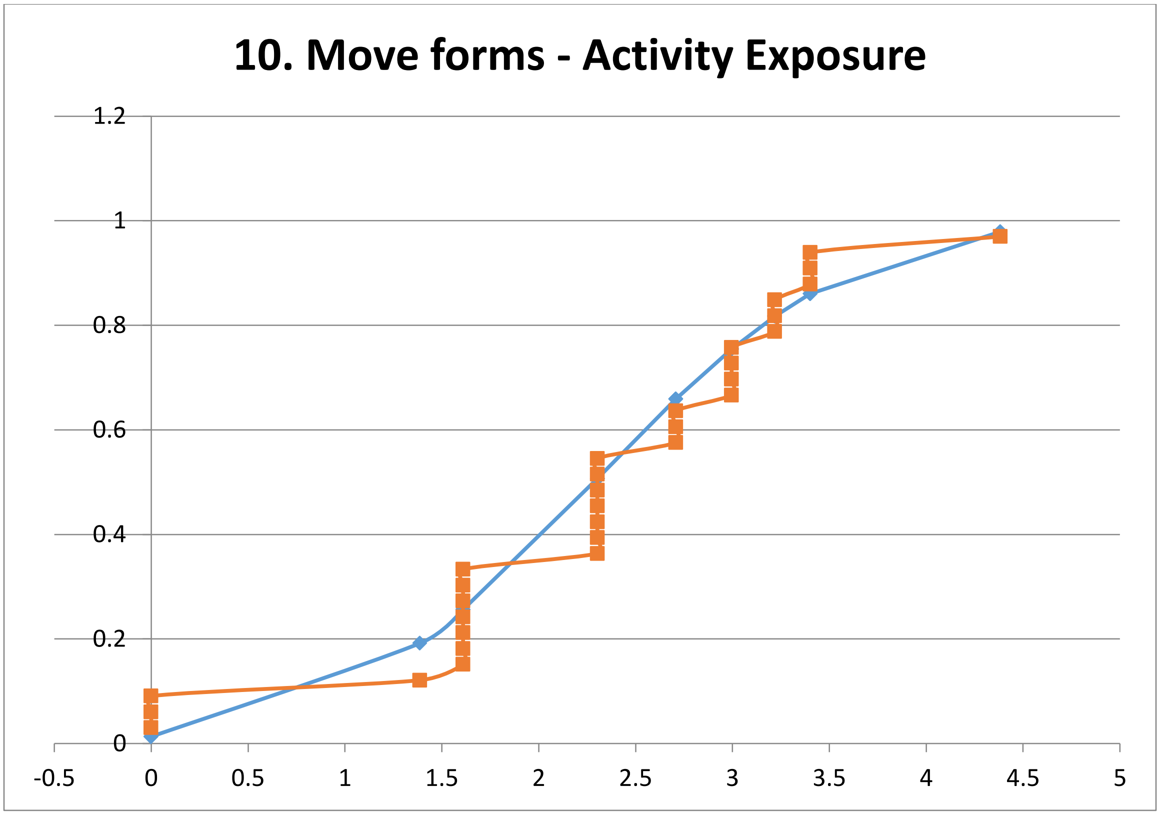

5. Stacking prepared forms - Activity Exposure
1.2
1
0.8
0.6
0.4
0.2
0
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5

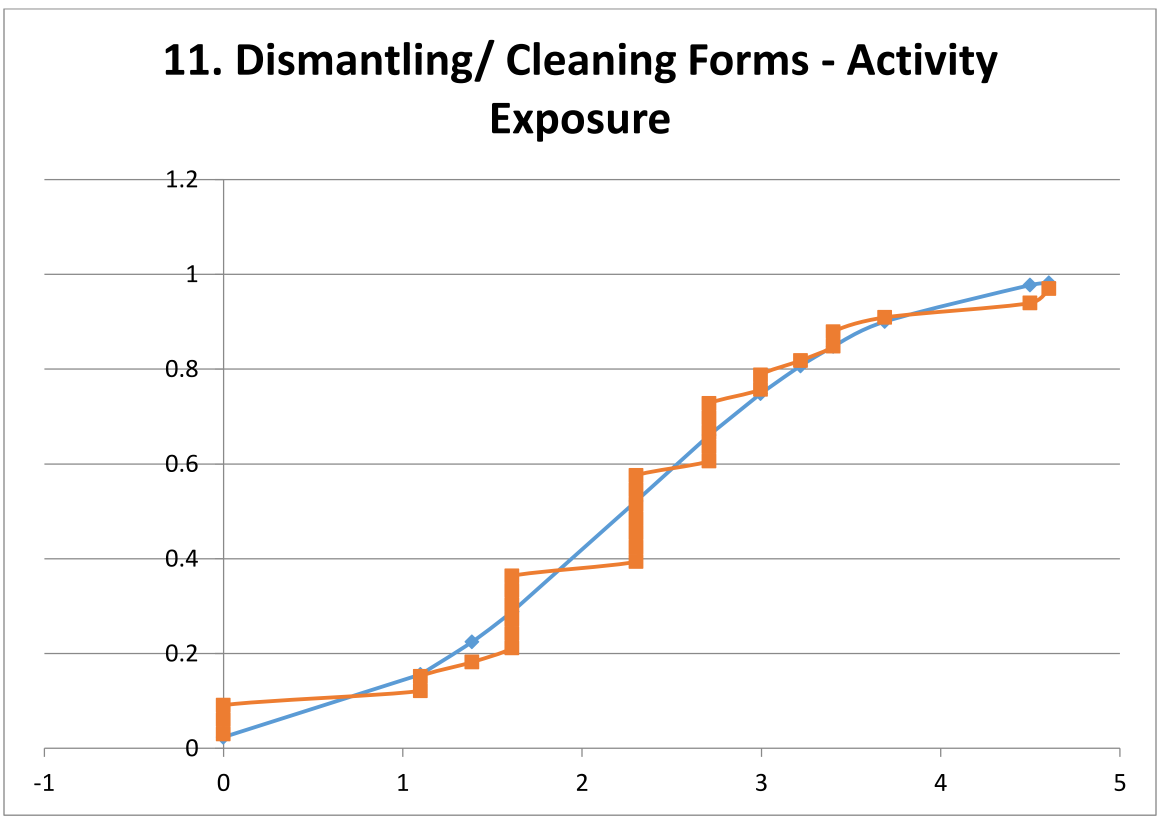

6. Moving - Activity Exposure
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-1
0
1
2
3
4
5

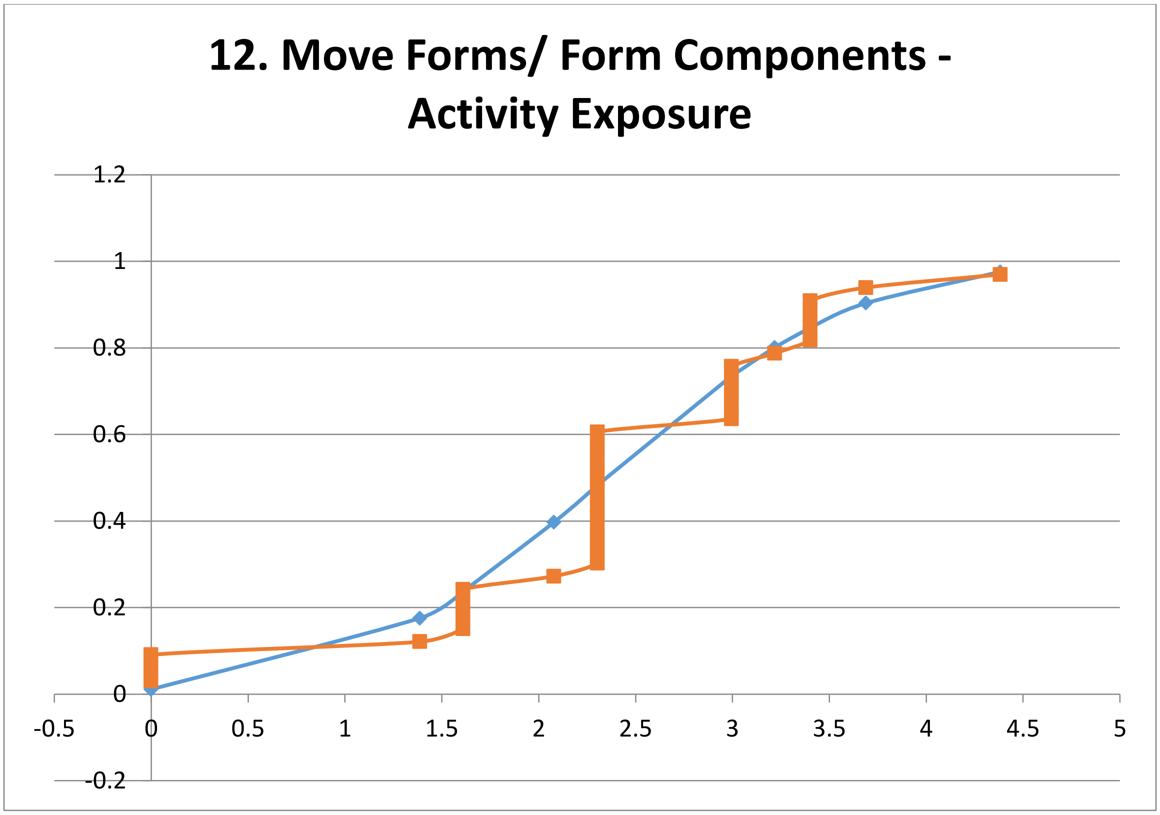

7. Erecting/Placing Forms - Activity Exposure
1.2
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

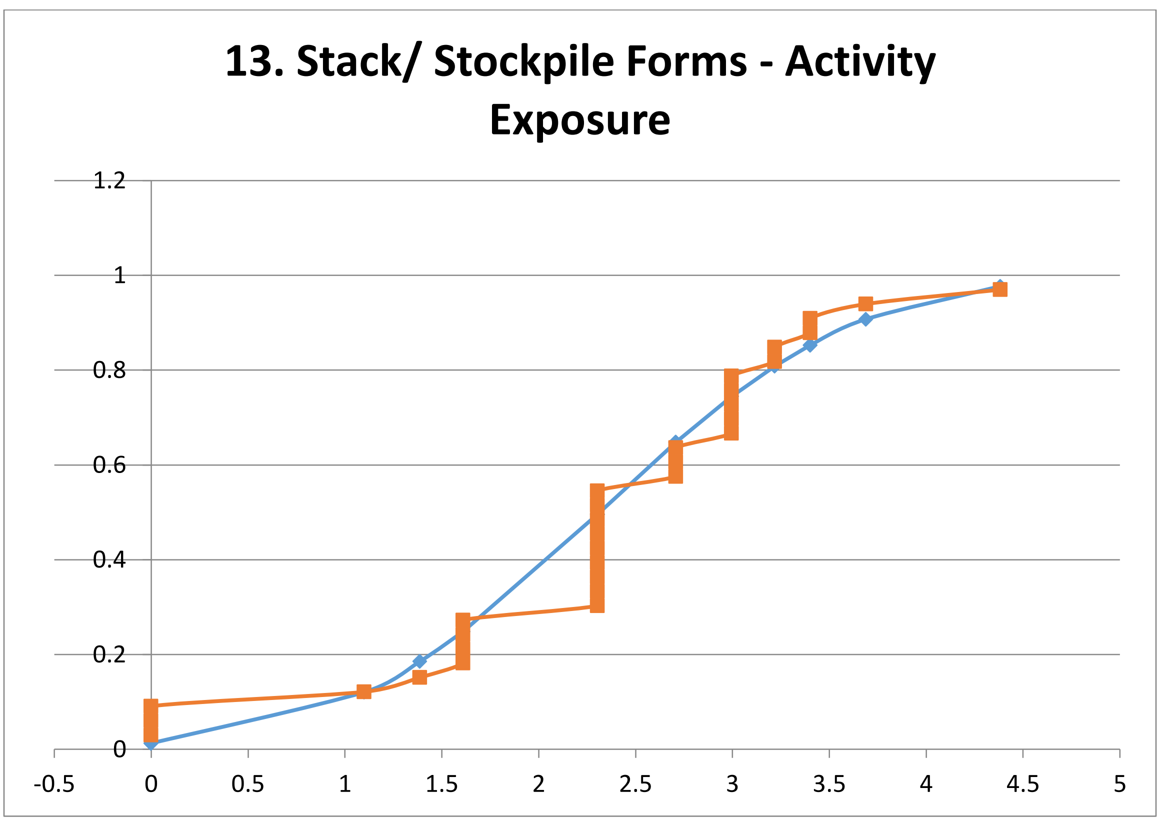

8. Pouring Concrete/ Curing - Activity Exposure
1.2
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5


9. Stripping Forms - Activity Exposure
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-1
0
1
2
3
4
5


10. Move forms - Activity Exposure
1.2
1
0.8
0.6
0.4
0.2
0
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5


11. Dismantling/ Cleaning Forms - Activity Exposure
1.2
1
0.8
0.6
0.4
0.2
0
-1
0
1
2
3
4
5


12. Move Forms/ Form Components - Activity Exposure
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5


13. Stack/ Stockpile Forms - Activity Exposure
1.2
1
0.8
0.6
0.4
0.2
0
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5