Project
Farnsworth House
14520 River Road
Plano, Illinois

Relocating / Elevating Study
TT Project No. C13103.00

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1.00 **EXECUTIVE SUMMARY**

The Farnsworth House was designed by Mies van der Rohe in the years 1945 through 1952 as a summer house on the Fox River in Plano, Illinois. It stayed a private residence until its purchase in 2003 by Landmarks Illinois, and later the National Trust for Historic Preservation, at which point it was opened to the public as a museum.

Mies designed the finished floor elevation to be just above the highest flood level, as determined by high water marks on the nearby bridge, but this elevation proved to be insufficient in 1954 when the first major flood infiltrated the house. At least three successive floods in the almost 60 years since have caused water to enter the house, and the lower terrace structure has been flooded at an even greater rate. Based upon studies and research done by FEMA, the Fox River Study Group, and Wright Water Engineers, it is clear that population increases since the initial construction have led to a larger area of hardscapes in the direct watershed of the Fox River. As a result, the increased water runoff has increased and exacerbated the issue. The population in the watershed is forecasted to continually grow over the next couple of decades, and thus it is reasonable to assume that the threat of flooding to the house will continue to increase.

Some sort of remediation, or budget consideration, is needed to reduce, eliminate, or tolerate the flooding hazard imposed on the house. It has been requested by the National Trust for Historic Preservation that Thornton Tomasetti (TT) develop and evaluate options. In total, nine options are discussed and their respective advantages and disadvantages are provided.

To provide an *order-of-magnitude* understanding of the financial implications, conceptual costs are included. An analysis of the structural frame, connections, and foundation system was completed to assess the viability of selected options, and to determine limitations. Further testing and analysis of the geotechnical and hydraulic conditions on-site will be necessary to further develop cost estimates and determine feasibility.
2.00 INTRODUCTION

2.01 FARNSWORTH HOUSE DESCRIPTION

The Farnsworth House is located in Plano, IL. The house – designed by Mies van der Rohe – was completed in 1952 for Dr. Edith Farnsworth, and was intended to be both a functional retreat for Dr. Farnsworth as well as a modern architectural work in the form of his newly developed International Style. As stated in the Historic American Building Survey, “the Farnsworth House represents the apex of Mies’ American career. Built as a country house for Edith Farnsworth, a single woman sympathetic to his aesthetic aims, the house comes as close as Mies ever came to achieving his vision of ‘beinahe nichts’ or ‘almost nothing,’ the reduction of every element to its essence.” It is also said, “The Farnsworth House, therefore, serves as a primer, a pellucid statement of the idea at the core of a global modern architectural movement.”

The house is composed of two principal components, the main house and the terrace connected to the south and west. The house is approximately 1,500 square feet and is composed of a structural steel frame with precast concrete panels with cast-in-place concrete infill at the floor level. The roof level is structural steel with precast concrete panels overlaid by roofing materials. There are 12 perimeter columns for the house and the terrace which support the vertical gravity load as well as provide lateral stability. The moment resisting connections between the columns and the wide-flange beams that span horizontally between them are field-welded to restrict rotation and provide rigidity, and thus resist lateral loads and sway.

The exterior façade – on all four sides – is single-pane glass that spans from floor to ceiling. The flooring is travertine and has an in-floor radiant heat system installed throughout the footprint of the home, with the exception of the utility spaces within the interior core. A utility trunk connects this core with the ground and provides an access point for services such as water, waste, electrical and plumbing. The trunk is constructed of flanged steel pipe and spans the distance from grade level to the bottom of the main floor of the house – about 4 feet.

2.02 SITE DESCRIPTION

The site was originally comprised of nine acres but has expanded to sixty-two acres. Although not included in the initial design, multiple auxiliary buildings have been constructed on-site since, which include a boathouse, a garage, a pool, and a tennis court – all of which still reside on the property today. A small visitor center sits at the new entrance, about half a mile from the residence. A smaller waterway known as Rob Roy Creek extends through the north portion of the site, and is crossed on the walk down from the Visitors Center. The vegetation directly around the
house is dominated by high-mown grass, which replaced the tall native grasses on the site when the house was constructed. There are a significant number of mature trees on-site including a few in the near vicinity of the eastern side of the house. The Black Sugar Maple “Witness” tree that was integral to the siting of the residence, serving as an aesthetic anchor, was removed last year as it was no longer stable.

The Farnsworth House was placed about 100 feet from the banks of the Fox River, and was done so because of Mies’ desire for the house to be connected with it, and to preserve views of the landscape in all directions. For this reason, the relationship between the house and the river is generally considered to be of great importance.

The topography of the site is relatively flat near the Farnsworth House, but gradually increases in elevation as the ground slopes to the north. This reaches a peak elevation near the level of River Road at approximately 580.5 ft. – or about 15 feet above the grade of the house. The site is in a rural area about 1.5 miles south of the city of Plano and is bordered by two roadways, River Road to the north and Fox River Drive to the west; the latter crosses the Fox River via a bridge just to the south of the site. There is also a dam in the Fox River just over a mile downstream from the house. Directly across the Fox River from the house is Silver Springs State Park.

A site plan is provided in Figure 1.

Background information on the hydrology of the site is provided in Appendix B.
**Figure 1**: Site Plan, with data from National Park Service
3.00 ASSIGNMENT

Thornton Tomasetti, Inc. was retained by the National Trust for Historic Preservation to evaluate options for mitigating the flood hazard imposed on the house and to provide basic cost assumptions for some of the options.

3.01 DOCUMENTATION REVIEW

TT relied upon multiple resources in order to develop a greater understanding of the history, design, construction, and maintenance of the Farnsworth House. Reviewed documents include the following:


- “Farnsworth House Photographs, Written Historical and Descriptive Data, Reduced Copies of Measured Drawings, Field Records”; prepared by Historic American Building Survey, National Park Service, Department of the Interior.


- Partial set of the original structural drawings for "House for Dr. Edith Farnsworth" dated July 21st, 1949; prepared by Myron Goldsmith. Drawing numbers included: {S1, S2}
4.00 STRUCTURAL STUDY OF THE FARNSWORTH HOUSE

TT evaluated the structure and key components, which affect various proposed options, in the following sections. A study of the code requirements, loads applied to the structure, analysis of the structural frame, connections, and foundations are provided within this section.

4.01 CODE REQUIREMENTS

The 2006 International Building Code (IBC) is the governing code provision in Plano, IL. It is one of the most widely adopted codes and it specifically discusses historic buildings listed on the National Register of Historic Places, or as so designated by other local or state institutions. Section 3407 addresses the construction, repair, alteration, addition, restoration and movement of structures. There are exemptions made for historic structures in the realm of handicap accessibility, stairway regulations, and changes to occupancy. These exemptions may apply to the alteration and/or movement of the Farnsworth House.

The IBC also indicates that guards are required at any open sided walking surface more than 30 inches above grade. The elevation of the main finished floor of the house is currently at 5 feet above grade which exceeds this provision. If the house is raised in-place without subsequent re-grading, the issue would only be exacerbated. The current condition presents a risk of falling especially since the facility has greatly increased its exposure to the public as it has undergone a change in occupancy from a private residence to a public museum. A temporary, removable barrier system could be considered for use when the building is accessed by the public. It should also be noted that historic buildings can often be exempted from these requirements.

4.02 LOADS

*Dead Load (DL)*

Dead loads used for the initial design are listed on S1 of the original drawings and are as follows:

- Roof Dead Load = 32 PSF
- Floor Dead Load = 125 PSF

The total self-weight of the house including the superimposed dead load is 549,000 lbs. or 275 tons (185 tons in the house and 90 tons in the terrace).
Live Load (LL)

Live loads used for the initial design are listed on S1 of the original drawings and are as follows:

- Roof Live Load = 25 PSF
- Floor Live Load = 40 PSF

The house was originally designed as a residential occupancy and it remained that way until its purchase in 2003, at which point it was officially designated as a museum. The magnitudes for applied live load based upon code requirements are different for these two occupancy types, but this difference is not considered for the purposes of this study as this provision is often not applicable to existing and historic structures.

Wind Load (WL)

The wind region dictates that design be based on a basic wind speed of 90 miles-per-hour which is based on a 3 second gust. Based upon these values, the wind load was determined to be as follows:

- Wind Load Y-Direction (North/South) = 11 PSF
- Wind Load X-Direction (East/West) = 11 PSF

Seismic Load (E)

The equivalent lateral force method was used to determine the magnitude of the effect a potential seismic event would have on the house. A resulting shear value at the base of the structure is determined which represents the total lateral force applied to the house. This base shear value allows for the distribution of lateral force to the terrace, main floor, and the roof levels based upon a weighted average of the mass and height of the structure. An analysis of the house when the equivalent static loads are imposed on it in accordance with the load combinations below finds that the structure generally has sufficient capacity to resist lateral seismic loads. However, when the effects of the terrace are included, the design capacity of the shared columns is exceeded. The lateral forces applied to the house in the current state are as follows:

- Lateral Force at Main Floor Level = 7.3 kip
- Lateral Force at Roof Level = 22.2 kip
- Lateral Force at the Terrace = 20.2 kip
Supplemental calculations are provided in Appendix D. These calculations include seismic forces for Options 2A, 2B, and 3B where the house is elevated above its current level.

**Load Combinations**

The following factored load combinations (LC) of the load cases presented above were used for analysis of the structure in order to determine the worst case scenario. They are referenced in ASCE/SEI 7 Section 2.3.

- LC1: 1.4DL
- LC2: 1.2DL+1.6LL+.5RLL
- LC3: 1.2DL+1.0LL+1.6WL+.5RLL
- LC4: 1.2DL+1.6RLL+.8WL
- LC5: .9DL+1.6WL
- LC6: 1.2DL+1.0E+1.0LL+.2SL
- LC7: .9DL+1.0E

### 4.03 Analysis of Elevating the Structure

Lateral loads applied by wind or seismic events are resisted by moment frames along both axes of the house at the column lines. There are 4 moment frames in the short direction of the house, and 2 in the long direction. The terrace leans on the house in the short direction and utilizes a similar moment frame system in the long direction. These frames also support gravity loads from the first floor, roof and terrace.

The loads discussed in the previous section were applied to an analytical model of the existing structure as well as the maximum elevated condition of the structure at 9.0 feet as proposed in Option 2B and 3B. The structural system has limitations to the height it can be elevated above its existing level, as doing so increases the bending force (moment) in the columns. If the structure were to be raised beyond a certain threshold, the columns could experience distortion under this increased bending force which leads to larger stresses at the welded connections between the columns and beams at the floor and roof levels. These increased bending forces also transfer to the footings, as the foundation has a rigid connection with the superstructure. It is necessary to analyze these columns when the house is elevated to ensure that they still have adequate axial
and moment capacity. This analysis was completed for the house when elevated to the maximum value proposed – 9.0 feet in Option 2B and 3B, and it was determined that the structural system generally has adequate capacity for the elevated options with the exception of the columns shared with the terrace in the case of seismic loads.

Figure 2 provides a schematic diagram of the structure of the house and how the loads are applied to it.

4.04 Analysis of Existing Connections

The connections of the columns to the interior beams at the locations of the moment frames are fully welded and therefore resist rotation. The connections of perimeter channel (C-Shape) beams to the columns are accomplished by welds at the top and bottom of the channels. There are also large plug welds that fill the bolt holes used during erection. The floor beams located on the column lines are rigidly connected to the columns through the perimeter channels such that they can resist lateral loads. The remaining infill beams are simply supported and are connected for gravity loads only.

Supplemental calculations are provided in Appendix D.

Details of the connections are provided in Figures 3 and 4.

4.05 Analysis of Existing Foundations

TT evaluated the current foundations based on the design loads and the allowable soil bearing pressure noted on the drawings. It appears that the foundations were designed utilizing an allowable bearing pressure increase when wind loads were applied. This methodology allows for the allowable bearing pressure to be increased by 33% when evaluating the foundations for the effects of wind and seismic loads and was commonly done years ago. However, the requirements for applying this methodology have changed since the Farnsworth House was designed, and the increase can no longer be used to offset the effects of the dead load of the structure. Based on the requirements of the current codes, the foundations are somewhat undersized.

Given the condition of the existing foundations, the addition of large volumes of fill soil to the site – if re-grading is done per selected options – will increase the overburden loads on the foundation which would be undesirable. A geotechnical study to evaluate the capacity of the soil could result in higher allowable bearing pressures and alleviate the issue. If a geotechnical evaluation shows
the allowable bearing pressure as indicated on the drawings is correct, retrofit of the foundations may be required to provide additional capacity for new loads. Further testing and analysis will need to take place to determine if the allowable bearing pressure can be increased.
Figure 2: Schematic Diagram showing how loads are applied to the house.
Figure 3: Detail of column-to-floor beam connection from original structural drawing set
Figure 4: Isometric views of column-to-floor beam connection
5.00 OPTIONS TO ADDRESS FLOOD HAZARDS

Four distinct groups of options with variations of each are provided as follows:

- **Group 1** – leave the house in place and/or make alterations to allow it to withstand flooding
- **Group 2** – elevate the house in place to various elevations above a design flood event level
- **Group 3** – move the house to various locations outside the flood plain
- **Group 4** – apply a technological solution to allow the house to adapt to the height of a design flood event

5.01 OPTION 1A – ALLOW THE HOUSE TO FLOOD

If the Farnsworth House is left in its current location at the existing elevation, the money not spent on alterations could be directly applied to an aggressive cyclical maintenance campaign.

Under flooding conditions, there are issues with exterior glass windows breaking under hydrostatic pressure applied to the exterior side of the façade, and travertine panels at the floor being damaged. Finishes would still need to be repaired once an event has occurred, but a majority of the movable elements of the house could be secured beforehand – as they are now – to prevent contact with flood waters.

This option could also include designating specific glass panels that could be designed to break once flood waters surpass the finish floor elevation and begin to apply lateral hydrostatic pressure to the exterior sides. Alternatively, the entrance doors at the west and operable windows at the east could be opened. This would allow the water to enter in a more manageable way that could limit damage to the remainder of the façade or the interior core.

**Pros**

- The house does not change and its contextual relationship with the site is not altered
- Little-to-no alteration of the existing building will need to be completed beyond repairs to damage
- Minimal upfront construction costs as no alterations are to be performed beyond repairs to damage
Cons

- The house will continue to be damaged by flood waters, and the damage in the future could be worse than that which has been previously sustained
- The structure’s lifespan would likely be decreased by continual damage
- Continual disruption of the operation of the house as a museum is likely
- Short and long-term maintenance and repair costs will be significant
- A more severe flood than has been previously experienced may cause significantly more damage to the house and its contents

5.02 OPTION 1B – MAKE THE HOUSE WATERTIGHT

With alterations, the Farnsworth House could be redesigned to withstand flood waters. The house could be made to be watertight and much more durable. Exterior façade windows would need to be replaced with higher strength glass panes that could resist the lateral loads imposed on them by the hydrostatic pressure of flood waters on only the exterior side, as well as flood debris potentially colliding with the glass. The thickness of this retrofitted glass pane is estimated to be about 1.5 inches, and composed of two layers of tempered glass with a laminated interlayer between. The entrance doors would present a challenge as it is difficult to develop a design that maintains their operability when the house is not flooded while also providing for a water tight seal when flooded.

The utility trunk below the house at the core would also need to be sealed in order to prevent water from flowing into the house – currently the manner in which water first enters the home during a flood event.

The Whitney Museum of American Art in New York City experienced a similar situation on-site as the elevation of the 500-year flood event was exceed during construction when Hurricane Sandy hit the region. The museum was redesigned after this event to be watertight and includes the use of temporary flood barricades and watertight glass to mitigate the threat of flooding.

Pros

- The house does not change and its contextual relationship with the site is not altered
- Long-term repair and maintenance costs could be decreased as a result of preventing water from entering the home
- Life span of the structure could be increased
• The operation of the house as a museum could conceivably continue uninterrupted after a flood event

**Cons**

• The exterior/interior of the house will still be subjected to flood waters
• The terrace will still be fully submerged during a 100-year event
• Construction costs could be prohibitively large as a complete retrofit of the house would be necessary and there are many unknowns
• Views from the house could be potentially altered by the addition of thicker glass to withstand flood loads
• Some design details of the house could be significantly altered in order to provide an appropriate seal during a flood event
• It may not be technically feasible to fully waterproof the house while meeting aesthetic expectations
• Water borne debris/missiles could still break the glass, if large enough, and cause flooding
• In-situ testing of the water-tightness of the revised design details will be difficult

5.03 **OPTION 2A – ELEVATE THE HOUSE AND TERRACE 6.5 FEET**

The Farnsworth House along with the terrace could be raised 6.5 feet. The corresponding finished floor elevation of 576.5 ft. (11’-9” above existing finish grade) would exceed the assumed 100-year design flood elevation which was determined to be at 572.0 ft. based upon the gauge analysis method performed by WWE. This elevation leaves the terrace below the flood level threshold, and means that the terrace would still see complete flooding during a 100-year event, but the house would not.

The elevation of 576.5 ft. is based upon a high flood water level of 574.0 which was seen in the crest of the 1996 flood where water reached a peak of about 4 feet above the existing finished floor. The 1996 flood was chosen as the baseline over the estimated 100-year elevation because it is 2 ft. higher than the current estimated 100-year flood elevation. An additional foot is added to this elevation to allow for freeboard – necessary to allow flood debris to pass underneath, as well as an allowance for the depth of the main floor structure which is 15 inches. Further investigation will be required to validate this elevation assumption, and it is important to note that the 1996 flood levels are estimated, not exact.
Figure 5 provides a reference for the development of the design flood elevation. A schematic elevation drawing of the house is provided in Figure 6 to further explain the increased elevation and its relationship with important benchmark flood levels.

In this scenario, the terrace should be re-detailed in a way that makes it more resilient in a situation where it is fully submerged. This would specifically address the attachment of the travertine panels to the deck as well as the overall drainage system of the terrace. As discussed in the field observations in Appendix C, the travertine panels in their current state are heaved and cracked at many locations, and this would provide the opportunity to make necessary repairs to bring them back to their original position and alignment as they were initially installed.

To restore the existing relationship between the house and the ground, and to prevent increasing the existing stair height, extensive re-grading may need to be undertaken. This would require a large amount of fill soil in order to cover the roughly 4 acres of flat terrain near the Farnsworth House. It would also bury many of the nearby trees to a level prohibitive to their survival, and could potentially have a significant impact on the hydraulics of the site and the surrounding area. There are also further complications with the nearby river bank elevation, the boathouse just to the southwest, and the existing foundations. Issues of settlement, erosion, and stabilization of the soil will also need to be considered and further researched. A hydrology investigation will need to be completed to fully understand the impact of these factors and their feasibility.

It may be determined, however, that the added height of the structure is aesthetically acceptable and within the original design intent without the added soil fill below it, and thus re-grading would not be necessary. A hybrid option of placing less fill soil on the site while simultaneously replacing the current turf grass with tall, natural prairie grasses that are native to the site and were in place at the time of construction may be considered. This would lessen the need for fill soil as it would increase the profile height of the finish grade level, and would close part of the gap left by the increase in elevation of the house. The native prairie grasses were replaced with the turf grass seen today by Lord Palumbo when he purchased the house.

In order to raise the structure, the columns will need to be uniformly cut at a specified height between the top-of-grade and the bottom of the main floor. The structure would be lifted with jacks and column extensions would be inserted (spliced) at these points. Extensions would be welded to the existing columns in a seamless manner so that no indication of the splice or weld is apparent. Mies had strict requirements for the finish and connection of the steel elements composing the house, and any alterations must comply with the standards set forth in the initial
design. This criterion would likely require significant grinding to finish the welds to an acceptable condition prior to painting.

This option likely will require the glass windows to be removed prior to jacking to avoid breakage due to the lifting procedure and stresses; this work item could be combined with the project to remove/re-finish the window stops in order to make the work more cost effective.

As stated previously, any modification to the height or location of the structure would likely require retrofit of the existing foundations or installation of new foundations in order to meet load capacity requirements. A geotechnical engineering study should be undertaken in order to obtain soil borings and evaluate acceptable bearing capacities and settlement characteristics that will consequently change with the addition of the overburden fill soil, and the increased height of the columns.

The utility trunk at the core of the house would be retrofitted to meet the increased height of the finish floor elevation. It may also be necessary to water proof the trunk to prevent it from filling with water during a flood.

Further, some retrofit or reinforcement of isolated columns and connections may be required to meet current seismic load requirements. It may be possible to retrofit of the lower sections of the columns by replacing the lower portion with a section of the same size but of higher strength.

**The conceptual opinion of cost of this option is estimated to be at $850,000; reference Appendix A for a cost breakdown which provides inclusions and exclusions.**

**Pros**

- The house remains at its original location on-site and will maintain a relatively similar contextual relationship with the Fox River
- It requires no lateral movement of the structure
- The likelihood of water reaching the finished floor elevation in the future will be less than the 100-year event commonly used in modern design practices and required by code, allowing for more consistent and lower cost operation of the museum and an increased lifespan for the structure
- The terrace can flood and be repaired on a shorter cycle
Cons

- A large amount of fill soil may be required to bring the site up to the new finished floor elevation to maintain the same relationship between it and the ground, and may lead to the destruction of site foliage
- The existing structure will be altered
- The view from the house of the river and nearby landscape and from the ground toward the house will be somewhat different than the views initially intended by Mies even if the site is regraded
- The terrace is still likely to flood during a 100-year event
- During a 100-year event, flood debris could damage the terrace as it will not have sufficient freeboard during complete submersion
- The utility trunk will be more prominent if the re-grading or prairie grass work is not performed
- Retrofit of the existing foundations will likely be required
Figure 5: Section isometric view showing relation of 1996 Flood elevation imposed on the house per Option 2A
Figure 6: South Elevation View showing Option 2A and its relation to important flood elevations
5.04 OPTION 2B – ELEVATE THE HOUSE AND TERRACE 9 FEET

The Farnsworth House along with the terrace could be raised 9 feet, which is approximately the maximum value the house can be elevated before the un-braced, existing column capacity is exceeded for non-seismic loads. The corresponding finished floor elevation of 579.0 ft. (14'-3" above finish grade) as well as the terrace elevation would exceed the assumed 100-year design flood elevation which was determined to be at 572.0 ft., based upon the gauge analysis method performed by WWE. This means that both the house and the terrace would not see flooding during a 100-year event.

The elevation of 579.0 ft. is based upon a high flood water level of 574.0 which was seen in the crest of the 1996 flood where water reached a peak of about 4 feet above the existing finished floor. The 1996 flood was chosen as the baseline over the estimated 100-year elevation because it is 2 ft. higher than the current estimated 100-year flood elevation. An additional foot is added to this elevation to allow for freeboard – necessary to allow flood debris to pass underneath, as well as an allowance for the depth of the main floor structure which is 15 inches. Further investigation will be required to validate this elevation assumption, and it is important to note that the 1996 flood levels are estimated, not exact.

Figure 7 provides a reference for the development of the design flood elevation. A schematic elevation drawing of the house is provided in Figure 8 to further explain the increased elevation and its relationship with important benchmark flood levels.

The conceptual opinion of cost of this option is estimated to be at $1,200,000; reference Appendix A for a cost breakdown which provides inclusions and exclusions.

Pros

- The house remains at its original location on-site and will maintain a relatively similar contextual relationship with the Fox River
- It requires no lateral movement of the structure
- The likelihood of water breaching the finish floor or terrace elevation in the future will be less than the 100-year event commonly used in modern design practices and required by code, allowing for more consistent and lower cost operation of the museum and an increased lifespan for the structure
- The terrace would not flood and therefore repairs/remediation would not need to be implemented
**Cons**

- A large amount of fill soil may be required to maintain the same relationship between the floor levels and the ground, and may lead to the destruction of site foliage
- The existing structure will be altered
- The view from the house of the river and nearby landscape and from the ground toward the house will be somewhat different than the views initially intended by Mies
- The utility trunk will be more prominent if re-grading is not done
- The cons presented here are similar to Option 2A, however they are exacerbated by the increased height
- If re-grading is not performed then a significant number of treads will need to be added to increase the height of the stair
- Retrofit of the existing foundations will likely be required
Figure 7: Section isometric view showing relation of 1996 Flood elevation imposed on the house per Option 2B
Figure 8: South Elevation View showing Option 2B and its relation to important flood elevations
5.05 **OPTION 3A – RELOCATE THE HOUSE ON-SITE TO AN ACCEPTABLE ELEVATION**

The Farnsworth House could be moved north on the existing site to a location with a grade-level elevation of at least 574.0 ft., which is about 300 feet north from where the house currently rests. This places the house at 9 feet above the current existing height which would protect it and the terrace from being flooded during a 100-year event. The resulting finished floor elevation of the house would be about 579.0 ft.

The elevation of 579.0 ft. is based upon a high flood water level of 574.0 ft. which was seen in the crest of the 1996 flood where water reached a peak of about 4 feet above the existing finished floor. The 1996 flood was chosen as the baseline over the estimated 100-year elevation because it is 2 ft. higher than the current estimated 100-year flood elevation. An additional foot is added to this elevation to allow for freeboard – necessary to allow flood debris to pass underneath, as well as an allowance for the depth of the main floor structure which is 15 inches. Further investigation will be required to validate this elevation assumption, and it is important to note that the 1996 flood levels are estimated, not exact.

A schematic section drawing of the house is provided in Figures 9, 10, 11, and 12 illustrate and further explain the revised location and its increased elevation, as well as its relationship to the site.

Extensive re-grading of the site will need to be undertaken to create a similar relationship between the finish grade and the house. A large volume of cutting and filling of soil will be needed to create a flat site to mimic the existing condition and profile. The north bank of the Fox River at below-flood-stage levels flows at about 100 feet to the south of the house. After being moved, this distance would increase to approximately 400 feet, and thus the resulting view and perspective from the house will change significantly. River Road will be much closer to the residence, only 200 feet away from the north side of house and could be seen and/or heard from the interior of the Farnsworth House. There is a pool about 50 feet to the northwest and a garage about 50 feet to the northeast. These facilities will need to be considered. Trees will need to be removed, and extensive re-grading could put other foliage not in the direct vicinity of the new location of the house at risk.

Moving the house itself is an extensive operation requiring severing the columns at their connection with the foundation, construction of new foundations at the new location, and moving the structure both vertically and laterally. Site utilities would also need to be re-located to the house after it has been moved.
The conceptual opinion of cost of this option is estimated to be at $1,400,000; reference Appendix A for a cost breakdown which provides inclusions and exclusions.

**Pros**

- The likelihood of water reaching the finished floor or terrace elevation in the future will be less than the 100-year event commonly used in modern design practices and required by code, allowing for more consistent and lower cost operation of the museum and an increased lifespan for the structure
- No permanent alterations would need to be made to the house beyond cyclical repairs
- The house would remain on the same site maintaining some of the original views as the existing location

**Cons**

- A large amount of cut soil will be required to be removed in order to adequately place the house on a level portion of an inclined hill, and to maintain the same relationship between it and the ground, and may lead to the destruction of site foliage
- An extensive operation will be required to move the house, which could result in damage to the house due to possible non-uniform displacements of the structure and the inherent risks of unforeseen conditions
- The views from the house of the river and nearby landscape will be different than the views initially intended by Mies.
- Site buildings will be in direct sight of the north side of the house
Figure 9: Site Plan showing revised location of the Farnsworth House per Option 3A
Figure 10: Profile Grade Section View showing existing location of the Farnsworth House versus the new location once moved per Option 3A.

Existing Profile Grade

New Profile Grade

Approx 300 feet
Figure 11: Photograph from inside the house looking south

Figure 12: (Left) Photograph showing perspective from re-located position based upon Option 3A, (Right) Photograph showing perspective from re-located position with house removed to show view of the Fox River
5.06 Option 3B – Relocate the House On-Site Near the Existing Location and Elevate 9ft

The Farnsworth House could be relocated on-site about 100 feet to the north of its existing location and raised 9.0 feet above the existing elevation. The corresponding finished floor elevation of 579.0 ft. as well as the terrace elevation would exceed the assumed 100-year design flood elevation which was determined to be at 572.0 ft., based upon the gauge analysis method performed by WWE. This means that both the house and the terrace would not see flooding during a 100-year event.

This option requires fill soil to be brought onto the site to raise the elevation of the area at the new location and thus significant grading will need to be performed. The house will still need to be elevated to meet the new height as it is assumed that the foundations will remain at the same elevation as they are now; doing so would prevent larger settlement from occurring as the foundations will not bear on newly placed soil.

Moving the house back 100 feet and elevating it 9.0 feet is a hybrid of both Option 2B and Option 3A. It provides adequate distance with which re-grading can be done to preserve the existing relationship between the house, the finish grade level, and the river, and increases the height of the house and terrace above the 1996 flood event. Setting the house back 100 feet allows for a gentle slope from the north bank of the Fox River to a plateau that is similar to the flat area between the house and the river that exists currently. This option maintains a similar setback distance and relationship to the site as it exists today and as Mies originally intended.

A schematic elevation drawing of the house is provided in Figures 13 and 14 to further explain the increased elevation and its relationship with important benchmark flood levels. Conceptual grading lines are shown however, all design of the re-grading of the site would need to be performed by an engineer who specializes in this area along with a landscape architect.

The conceptual opinion of cost of this option is estimated to be at $1,700,000; reference Appendix A for a cost breakdown which provides inclusions and exclusions.

Pros

- The house maintains a similar relationship with the existing site and the Fox River by preserving the distance between the south edge of the house and the leading edge of the north bank of the Fox River
- The likelihood of water reaching the finish floor elevation in the future will be less than the 100-year event commonly used in modern design practices and required by code,
allowing for more consistent and lower cost operation of the museum and an increased lifespan for the structure

- The current height of the utility trunk will be maintained

**Cons**

- The views from the house of the river and nearby landscape will be different than the views initially intended by Mies.
- Site utilities will need to be relocated to the new position of the house
- The boathouse may need to be relocated
Figure 13: Site Plan showing revised location of the Farnsworth House per Option 3B

x = the relationship (distance) between the slope edge of the river bank and the southern most edge of the terrace
Figure 14: Profile Grade Section View showing existing location of the Farnsworth House versus the new location once moved per Option 3B

Existing Profile Grade

New Profile Grade

x = the relationship (distance) between the slope edge of the river bank and the southernmost edge of the terrace
5.07 **OPTION 3C – RELOCATE THE HOUSE OFF-SITE**

The idea that the Farnsworth House could be moved off-site to a location such as Chicago, IL that does not have issues with flooding has been discussed in the past. This process would include detaching the structure from its existing foundations, placing it on a shipping truck, transporting it to a new site, and placing on a new foundation. The house would need to be separated into multiple sections for transport. Furthermore, the structure was not designed to be disassembled and the many welded components would make this difficult. This would likely result in the complete dismantling of the house. It is doubtful that this is a viable option as the costs incurred would likely be prohibitive and roadway restrictions may not permit travel across necessary bridges and highways. The width restriction for a transport truck is 8'-6” which would require the house itself to split into four separate widths. The length restriction is 28'-6” which would require the house to be split into three separate lengths. The house would need to be split into twelve pieces total and the terrace into six pieces; a total of eighteen pieces.

**Figure 15** provides details on shipping truck size requirements and limitations for Illinois roadways which show that the height of the house itself might not meet clearance requirements for passing under bridges in route.

The Farnsworth House could also be placed upon a barge in the nearby Fox River, and transported to a nearby location with a similar site, but with an elevation above the floodplain. Considerations for moving the house by means of floatation include the required river depth for floatation, clearance below bridges, and dams that may prevent passage.

**Pros**

- The house would be accessible to a large number of people if moved closer to an urban center
- The house would not be subject to flooding

**Cons**

- It would be necessary to purchase new land or establish a lease agreement
- Moving the house would remove its contextual relationship with the site and the river; the house was meant to be a rural summer home, and not set to be in an urban environment
- The house would have to be disassembled into a multitude of pieces making reassembly difficult and cost prohibitive
- The costs of moving the house in fewer sections would be prohibitive
• The house would be subjected to an immense amount of de-construction/construction increasing the chances of damage
• An extensive public relation campaign would be required to ease the concerns of interested parties and stakeholders
• Limitations of truck transportation may prevent the house from being shipped in large sections and would thus necessitate breaking the house down into an unmanageable number of pieces
• Some elements would likely need to be completely replaced including the radiant heat system, electrical wires running through the floor, and the plenum system in the ceiling
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<td>Special Haul Vehicles on all Above Categories</td>
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Notes:

*1 65 feet overall length (bumper to bumper) and/or 55 feet from center of front axle to center of rear axle.

*2 Tandem is defined as any 2 or more single axles whose centers are more than 40 inches and not more than 96 inches apart, measured to the nearest inch between extreme axles.

*3 See Tables II and III.

*4 Applies on semitrailers longer than 48 feet.

*5 55’ on Local Roads and Streets, 65’ from designated State Highway (5 mile access law).

*6 Gross weight is determined by measuring to the nearest foot between extreme axles. (See Table II)

Exceptions to WIDTH requirements above:

- Does not include certain safety devices approved by Department.
- Width restrictions do not apply to vehicles transporting implements of husbandry operating in the daytime. Loads of hay, straw or other similar farm products are limited to a maximum of 12 feet.
- A recreational vehicle may exceed 8’ 6” if the excess width is attributable to appurtenances that extend 6’ or less beyond either side of the vehicle body.

Exceptions to LENGTH requirements above:

- Length limits do not apply to vehicles operating in the daytime except on Saturdays, Sundays or legal holidays when transporting poles, pipes, machinery or other objects of a structural nature which cannot be readily disassembled, provided the length of the object being transported does not exceed 80 feet and the overall length of vehicle and load does not exceed 100 feet.
- Stinger-steered vehicles specifically designed to transport motor vehicles or boats may have an overall length of 75 feet plus overhang of 3 feet in front and 4 feet in the rear on Class I and II highways.
- Conventional auto transporters are vehicles specifically designed to transport motor vehicles or boats may have an overall length of 65 feet plus overhang on these highways. The maximum overall length on all other streets and highways is 60 feet.

General exceptions to above Table:

- All large vehicles operating on Class I highways shall have access for a distance of one mile on any street or highway to points of loading and unloading, and facilities for food, fuel, rest and repair.
- Large vehicles operating on designated state highways shall have access for a distance of 5 highway miles on any other state highway and on designated local streets and highways, to points of loading and unloading, and facilities for food, fuel, rest and repair. (This applies only on local streets and highways specifically designated and posted by local officials.)
- Permits may be issued for overdimensional objects and vehicles if they have been reasonably disassembled. Multiple objects loaded side-by-side, end-to-end, or on top of each other may not cause the overdimension.
- Streets or highways are designated by the Department of Transportation or local officials having jurisdiction.

Maps of the designated state truck route system are available at www.gettingaroundillinois.com

Figure 15: Illinois Department of Transportation Maximum Legal Dimensions
5.08 **OPTION 4A – EMPLOY A MECHANICAL / HYDRAULIC SYSTEM TO RAISE THE HOUSE DURING FLOODING**

The Farnsworth House would be outfitted with a mechanical/hydraulic system which would elevate the columns – and thus the entire structure – to a point above flood water level temporarily prior to or during an event. This system would then lower the structure back to its existing elevation once waters have receded. It would be installed beneath the column bases below grade so as not to be seen at ground level. It will likely be necessary to move the house temporarily so that such a system could be constructed.

TT has reviewed a brief study commissioned by Dirk Lohan on this approach in which the study concluded that two options were feasible; a hydraulic lift system and a screw jack system. While engineering analysis and design were not performed to validate this proposal, it serves as a possible option to explore further if this option is deemed practical.

Any system that raises the house will need to have sufficient lateral stiffness to resist lateral loads such as wind and flowing water.

The system itself would require a main source of power that is independent of the house, and would likely be at a higher voltage than the main service provided to the house now. Depending upon the site power capabilities, a generator will likely be necessary to provide a backup power supply in the event that the flood renders the primary source unavailable.

**Pros**

- The house could be elevated to a greater and variable height based upon the level of flood waters
- The home would not be altered aesthetically and would maintain the same contextual relationship with the site as initially intended

**Cons**

- Mechanical systems such as the one proposed requires significant resources to operate and maintain, and these resources may not be available or desirable
- An extensive and costly operation will be required to construct the system and connect it to the house
- The cost for initial construction as well as long-term operation and maintenance can be prohibitive
- Failure of the system to operate during a flood would result in damage to the house
5.09  **OPTION 4B – EMPLOY A BUOYANT SYSTEM TO ALLOW THE HOUSE TO NATURALLY RISE DURING FLOODING**

The Farnsworth House could be designed to be buoyant during a flooding event. This would allow the structure to rise in elevation in concert with the flood waters. It would then be lowered after the flood waters recede to the point of its original elevation. The system could be designed such that it is minimally visible, with most of the system below grade.

In order to construct the system, the house would need to be temporarily moved from its current location. After construction, the house would be relocated to its former position. The utility connections would need to be redesigned in order to rise and lower with the house without damage.

This type of system would involve creating a below grade tank or “bathtub” that would house a float, on which the house would be supported. During flood conditions, the tank would fill with water which would cause the house to float up, this water could be the flood water itself or water intentionally pumped in prior to the arrival of floodwaters. Within the tank, guides would be required to keep the float aligned within the tank. To prevent the float from rising out of the tank, stops would be required at the top of the tank. When flood waters recede, the tank would be pumped out at a controlled rate to lower the house back down to its former level.

During times of minor flooding, where the water levels will not reach the level of the terrace or 1st floor, the float could be ballasted with water to prevent the house from rising. Other design considerations would include: sizing the tank such that it is not buoyant itself, allowing for access to the tank for cleaning/flushing out debris after a flood, and evaluation of the terrace to determine whether it is floated with the house or separated such that the house floats and the terrace does not.

The August 2013 issue of Engineering News Record (ENR) includes an article featuring examples of this type of buoyant system. The solutions presented in this article are similar to the option provided here as shown in Figure 16. It is important to also note that the article states that, as of now, a buoyant structure does not qualify for lower FEMA flood insurance rates because the elevation is not changed permanently.

**Pros**

- The house could be elevated to a higher and variable height based upon the level of flood waters
• The home would not be altered aesthetically and would maintain the same contextual relationship with the site as initially intended
• Mechanical equipment would not be necessary to raise/lower the house

Cons

• Buoyant systems such as this take significant resources to operate and maintain, and these resources may not be available or desirable
• An extensive and costly operation will be required to construct the system and connect it to the house
• The cost for initial construction as well as long-term operation and maintenance can be prohibitive
• Failure of the system could result in significant damage to the structure if differential lift in the columns occur, or is the structure does not raise accordingly and water enters the house
**Figure 16:** Schematic sketch of potential buoyant system
### 5.10 Option Summary

*Figure 17* provides a summary chart listing the pros and cons of each respective option.

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<th>Cons</th>
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</thead>
<tbody>
<tr>
<td>Relationship between house and site does not change</td>
<td>House will continue to be damaged by flood waters</td>
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<tr>
<td>No alterations are made to the house</td>
<td>Lifespan of house would be decreased by continual damage</td>
</tr>
<tr>
<td>Lower upfront construction costs</td>
<td>Disruption of museum operation for repairs after flooding</td>
</tr>
<tr>
<td>Lower long-term maintenance fees</td>
<td>High upfront construction costs</td>
</tr>
<tr>
<td>Increased lifespan of the structure</td>
<td>High long-term maintenance fees</td>
</tr>
<tr>
<td>Continual, uninterrupted operation of the museum</td>
<td>View shed from the house will change</td>
</tr>
<tr>
<td>House will not be subjected to flood waters</td>
<td>Original design and/or intent will be altered</td>
</tr>
<tr>
<td>Terrace will not be subjected to flood waters</td>
<td>Flood waters will enter the house</td>
</tr>
<tr>
<td>House will not be moved from original location on-site</td>
<td>Flood waters will submerge the terrace</td>
</tr>
<tr>
<td>House will be accessible to a larger population of people</td>
<td>Large amount of re-grading is necessary</td>
</tr>
<tr>
<td>Mechanical system is not employed</td>
<td>Site building / road will be in direct sight of house</td>
</tr>
<tr>
<td>Failure of system is possible</td>
<td></td>
</tr>
</tbody>
</table>

*Figure 17*: Summary chart of pros / cons for each option
6.00 NEXT STEPS

Thornton Tomasetti recommends the following consultants be retained to develop a better understanding of the existing conditions on-site and their limitations:

- Hydraulic Engineering – to determine the extents of a revised flood plain based upon projected population increases and the respective flood event elevations pertinent to design, as well as the impact any re-grading would have on the flood plain.

- Geotechnical Engineering – to determine the bearing capacity of the soil on-site in order to conclude whether foundation retrofit is necessary due to alterations of the structure, as well as design of new foundations if applicable.

- Landscape Architecture – to determine the impact any re-grading would have on existing foliage, and methods for maintaining the original site conditions after any sort of alteration has been completed.

- Site, Civil Engineering – to determine appropriate and feasible methods for re-grading the site as proposed in the options of this report, as well as methods for mitigating erosion and sediment runoff.
LIMITATIONS AND SIGNATURES

This report shall not be construed to warrant or guarantee the building and/or any of its components under any circumstances. Thornton Tomasetti shall not be responsible for latent or hidden defects that may exist, nor shall it be inferred that all defects will have been either observed or recorded. Thornton Tomasetti’s report shall not constitute a detailed specification for elevating or moving the house, performing any repairs, or sufficing for permit application.

Conditions noted in this report are as of the time of examination only. It can be expected that the subject building will undergo changes and additional deterioration subsequent to that date.

The engineering conceptual opinions of cost provided in this report have been prepared by TT and not a cost systems expert, and are not intended to serve as a construction cost estimate for the work described.

This report was prepared by Mr. Kevin Jackson and Mr. Kyle Vansice under the direction of Mr. William D. Bast, P.E., S.E., SECB of Thornton Tomasetti, 330 North Wabash Avenue, Suite 1500, Chicago, IL 60611, Telephone: 312.596.2000.

Respectfully submitted,

THORNTON TOMASETTI, INC.

__________________________
Kyle Vansice, EIT
Engineer Intern

__________________________
Kevin Jackson, PE
Senior Associate

__________________________
William D. Bast, SE, PE, SECB
Principal
Appendix A: Conceptual Cost Details and Breakdown
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1.04 Option 3B – Relocate the House On-Site Near the Existing Location and Elevate 9ft.............. 7
1.00 Conceptual Cost Analysis

Four options have been further discussed in terms of their potential costs; it is important to note that the detailed cost breakdowns and final value are conceptual estimates, and should not be relied upon in determining schematic construction costs. They are merely a ballpark figure meant to provide an order-of-magnitude understanding of the costs associated with these options. A list of inclusions is provided for each in order to explain the means and methods considered in construction, as well as a list of exclusions to provide items not included in the conceptual estimates provided here.

1.01 Option 2A – Elevate the House 6.5 Feet

Figure A1 provides a conceptual cost breakdown and summary of the total estimated price. Items included in this estimate are provided in greater detail below:

- **Soil Borings and Analysis** includes the development of a geotechnical report which provides soil stratum data for the site as well as determines the soil bearing and existing footing capacity

- **Structural Review & Design** includes analysis of the existing structure and design of the column extension inserts and the welded connections

- **Design & Fabrication of Temporary Support System** includes the design of a bracing system to stabilize the structure – while the columns are cut from the foundation – as well as support multiple lifting apparatus during the elevating procedure itself

- **Equipment Rental** includes the rental of multiple hydraulic lifting apparatus, the temporary support system, welders, grinders, polishers, and steel cutting devices

- **Construction Fees and Permitting** includes an assumed 10% fee for the contractor to perform the work which includes costs of any potential permits required for the process of lifting the house

- **Equipment Mobilization** includes transporting the equipment to be rented to the site, loading and unloading, and preparation for use

- **Cutting of Columns from Foundation** includes severing the column at the specified location once the temporary bracing has been installed
• Elevating Process includes the removal of existing exterior glass at the façade, installation of the temporary support system, installation of multiple hydraulic lifting apparatus, miscellaneous field preparation of the structure, disconnecting utilities, measured & controlled lifting of the structure itself, and stabilization once at the desired height.

• Inserting Column Extensions and Welding includes the preparation of the column for welding, insertion of the column extension (and the column extension steel itself), and specialized welding to splice the new portion of the column with the existing.

• Finish, Polish, and Repaint includes the grinding of the splice weld smooth and flush with the column face, polishing of the welded area, and repainting according to the original design requirement so as to remove any visual trace of the column splice.

• Regrading of the Site at New Location includes the addition of fill soil and grading.

• Equipment Demobilization includes the disassembly of the temporary support bracing system of the structure, loading and unloading, and transportation of rented equipment back to point of origin.

• Punchlist Items includes replacement of the exterior windows at the façade, and any repairs to damage that occurred during the lifting process.

• Contingency includes a 20% of the total cost allowance for unforeseen conditions, and to provide a factor of safety for the total overall conceptual cost.

Items excluded in this estimate are provided in greater detail below:

• Excludes the design and construction of new footings if the existing foundation system is deemed to have inadequate capacity.

• Excludes the relocation or extension of the utility services due to the increased height of the house.

• Excludes all alterations to the utility trunk due to the increased height of the house.

• Excludes any mechanical, electrical, plumbing upgrades to bring the house into current code compliance if deemed necessary.

• Excludes design and implementation of fall protection at leading edges of the house.
• Excludes repairs to structure based upon damage not directly incurred during the operation of lifting the house

1.02 **OPTION 2B – ELEVATE THE HOUSE 9 FEET**

**Figure A2** provides a conceptual cost breakdown and summary of the total estimated price. The items listed as inclusions and exclusions for Option 2A also apply similarly to Option 2B, and thus are not included here. The cost difference between the two is a result of some activities being larger in magnitude, and therefore they are estimated to be more costly.

1.03 **OPTION 3A – RELOCATE THE HOUSE ON-SITE TO AN ACCEPTABLE ELEVATION**

**Figure A3** provides a conceptual cost breakdown and summary of the total estimated price. Items **included** in this estimate are provided in greater detail below:

- **Soil Borings and Analysis** includes the development of a geotechnical report which provides soil stratum data for the site, and design of a new foundation system to support the house at its new location on-site
- **Structural Review & Design** includes analysis of the existing structure and design of the column extension inserts and the welded connections, and the ability of the structure to be moved along required path for relocation
- **Design & Fabrication of Temporary Support System** includes the design of a bracing system to stabilize the structure – while the columns are cut from the foundation – as well as support multiple lifting apparatus during the elevating procedure itself, and transportation devices to move the structure to the new location
- **Equipment Rental** includes the rental of multiple hydraulic lifting apparatus, transportation devices to move the structure, the temporary support system, welders, grinders, polishers, steel cutting devices,
- **Construction Fees and Permitting** includes an assumed 10% fee for the contractor to perform the work which includes costs of any potential permits required for the process of lifting the house
- **Equipment Mobilization** includes transporting the equipment to be rented to the site, loading and unloading, and preparation for use
• **Cutting of Columns from Foundation** includes severing the column at the specified location once the temporary bracing has been installed

• **Regrading of the Site at New Location** includes the removal of approximately 7000 cubic yards of soil at the new location of the house on-site

• **Relocation Process** includes the removal of existing exterior glass at the façade, installation of the temporary support system, installation of multiple hydraulic lifting apparatus, installation of transportation devices, miscellaneous field preparation of the structure, disconnecting the utilities and the utility trunk, measured & controlled lifting of the structure itself, preparation of the path in which the house will be transported on, transportation of the house on-site to its new location, and stabilization once at the desired location

• **New Foundation Construction and Baseplates/Anchor Bolts** includes the excavation of the foundation area, labor and materials for setting rebar and pouring concrete footings, labor and material for setting baseplates and anchor bolts, permanent positive attachment of existing house columns to new foundations at baseplates

• **Equipment Demobilization** includes the disassembly of the temporary support bracing system of the structure, loading and unloading, and transportation of rented equipment back to point of origin

• **Punchlist Items** includes replacement of the exterior windows at the façade, and any repairs to damage that occurred during the lifting process

• **Contingency** includes a 40% of the total cost allowance for unforeseen conditions, and to provide a factor of safety for the total overall conceptual cost

**Items excluded** in this estimate are provided in greater detail below:

• Excludes soil stabilization and compaction if deemed necessary at the new location of the house on-site

• Excludes soil stabilization and compaction for the transportation path if deemed necessary

• Excludes the relocation or extension of the utility services due to the new location of the house
• Excludes all alterations to the utility trunk due to the new location of the house
• Excludes any mechanical, electrical, plumbing upgrades to bring the house into current code compliance if deemed necessary
• Excludes design and implementation of fall protection at leading edges of the house
• Excludes repairs to structure based upon damage not directly incurred during the operation of lifting the house

1.04 Option 3B – Relocate the House On-Site Near the Existing Location and Elevate 9ft

Figure A4 provides a conceptual cost breakdown and summary of the total estimated price. The items listed as inclusions and exclusions for Option 2A and 3A also apply similarly to Option 3B, and thus are not included here.
Items excluded in this estimate are provided in greater detail below:

- Excludes soil stabilization, erosion control, and compaction of the site
- Excludes retrofit of existing footings or construction of new footings
- Excludes the relocation or extension of the utility services
- Excludes all alterations to the utility trunk
- Excludes any mechanical, electrical, plumbing upgrades
- Excludes design and implementation of fall protection at leading edges of the house
- Excludes repairs to structure based upon damage not directly incurred during the operation of lifting the house
Items *excluded* in this estimate are provided in greater detail below:

- Excludes soil stabilization, erosion control, and compaction of the site
- Excludes retrofit of existing footings or construction of new footings
- Excludes the relocation or extension of the utility services
- Excludes all alterations to the utility trunk
- Excludes any mechanical, electrical, plumbing upgrades
- Excludes design and implementation of fall protection at leading edges of the house
- Excludes repairs to structure based upon damage not directly incurred during the operation of lifting the house

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| Total                                      | $310,000.00 | $780,750.00 | $129,500.00 | $1,200,000 |

Figure A2: Conceptual Cost Analysis for Option 2B
Items excluded in this estimate are provided in greater detail below:

- Excludes soil stabilization, erosion control, and compaction of the site
- Excludes soil stabilization and compaction for the transportation path
- Excludes the relocation or extension of the utility services
- Excludes all alterations to the utility trunk due
- Excludes any mechanical, electrical, plumbing upgrades
- Excludes design and implementation of fall protection at leading edges of the house
- Excludes repairs to structure based upon damage not directly incurred during the operation of lifting the house
Items **excluded** in this estimate are provided in greater detail below:

- Excludes soil stabilization, erosion control, and compaction of the site
- Excludes soil stabilization and compaction for the transportation path
- Excludes the relocation or extension of the utility services
- Excludes all alterations to the utility trunk due
- Excludes any mechanical, electrical, plumbing upgrades
- Excludes design and implementation of fall protection at leading edges of the house
- Excludes repairs to structure based upon damage not directly incurred during the operation of lifting the house

### Figure A4: Conceptual Cost Analysis for Option 3B

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**Figure A4**: Conceptual Cost Analysis for Option 3B
Appendix B: Hydrology Information
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<td>2.00</td>
<td>HYDROLOGY</td>
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1.00 FLOOD HISTORY

According to the report by Wright Water Engineers (WWE), the Farnsworth House has flooded at least 4 times since its construction. The first flood occurred in 1954 with the water height reaching about 2 feet above the finished floor elevation. The highest water levels recorded were in 1996 when the high-water mark was approximately 4 feet above the finished floor. The house was subsequently subjected to a flood water height of 1.5 feet above the finished floor in 2008, and then most recently a few inches below the finish floor elevation in early 2013. The number of occurrences of the terrace flooding is not known; however, it is subjected to flood waters much more frequently than the house proper as it rests at an elevation close to the 25-year flood level – about 2.5 feet below the finished floor elevation of the house. This threshold is important because it is the common baseline for design to meet code requirements for new construction. Based upon statistical analysis performed by WWE, the Farnsworth House – as it currently exists – can be expected to flood once every 20 years (or a 5% probability of annual exceedance). In reality – since its construction – it has flooded once every 15 years on average.

2.00 HYDROLOGY

TT reviewed the report by WWE regarding the hydrology of the area and flood hazards imposed upon the Farnsworth House; a brief summary of pertinent information to our scope is given here.

Mies van der Rohe understood that the choice of location on the site placed the Farnsworth House within the direct floodplain of the Fox River. Acknowledging the risk of flooding, “Mies requested information from the Illinois State Water Survey concerning the highest flood stages of the Fox River. Informed that such records were not kept, he was advised to “interview old settlers in the vicinity.” He decided to set the top of finished floor five feet above grade, two feet higher than the highest recorded stage reported by the old-timers.” This elevation was clearly inadequate, as made evident in 1954 when the house flooded with 2 feet of water. According to WWE, over time the issue has been exacerbated by population increases in the watershed areas that directly runoff and flow into the Fox River upstream from the house. The resulting increase in paved surfaces and other hardscapes from higher density populations leads to greater runoff flow levels which in turn increase the relative design flood level elevation. The most current 100-year flood elevation sits almost level with the finish floor elevation of the house. However, this estimate is based upon data obtained from the early 1980’s for the FEMA Flood Insurance Study (FIS) and does not take into account this increase in population. Furthermore, the Fox River Study Group has predicted that the population of these adjacent areas is expected to increase by 30% over the next 20 years, leaving the current estimated level considerably more inadequate.
WWE implemented an analytical method known as gauge analysis in order to predict a more likely accurate design flood elevation based upon current flow rates of the Fox River. This method relies upon data from stream gauges which measure the flow rate of a river over a certain period of time. If the flow rates increase consistently and substantially, then it is reasonable to assume that the design flood elevation has increased. WWE compared flow rates recorded at the time of construction with current values to determine a more accurate design flood elevation. The gauges that were relied upon for this analysis were several miles downstream of the Farnsworth site, and therefore a factor was applied to take into account the difference in surface area – known as an area adjustment. The predicted, revised increase in elevation of the design flood by WWE also explains the divergence between the expected probability of the home flooding once every 100 years versus the reality of it flooding once every 15 years on average. This method has been checked and validated; however, as WWE acknowledges in their findings, a more thorough and comprehensive hydraulic analysis must be completed to develop a truly reliable design flood elevation.

WWE recommends that in order to raise the house above the 100-year design flood elevation as estimated by gauge analysis, it would need to be elevated by 3 feet. This value includes 1 foot of freeboard between the bottom of the house and the top of the predicted 100-year flood waters to allow debris to safely pass underneath.

WWE also summarized a set of options for potential flood remediation which include doing nothing and allowing the house to continually flood, relocating the house, improving the river channel to allow for more unrestricted water flow, raising the elevation of the house, construction of a flood wall or levee, and clearing the area of debris. According to WWE however, none of these options are ideal as either they fail to adequately lessen the exposure of the house to the threat of flooding, or the cost-benefit ratio is prohibitive.

Figure B1 provides a visual summary of the FIS, Gauge Analysis, and historical flood elevations, along with important site elevations.
FIS: Flood Insurance Study, performed by FEMA
GA: Gauge Analysis Method for Estimation of Flood Plain, performed by Wright Water Engineers

**Figure B1:** Hydrology Graph summarizing findings of Wright Water Engineers report
Appendix C: Site Observations
TABLE OF CONTENTS – APPENDIX C

1.00  SITE OBSERVATIONS .................................................................................................................. 3
1.00 **SITE OBSERVATIONS**

Representatives of Thornton Tomasetti traveled to the Farnsworth House on July 1, 2013. This observation of conditions on-site was completed in conjunction with Ms. Ashley Wilson of the National Trust for Historic Preservation. The goal of this visit was to gain an understanding of the house in its current condition, and to develop a sense of the contextual relationship between it and the site. At the time of this visit, there was no flooding or standing water on-site; however the water elevation of the Fox River was elevated according to site staff (*Figure C1*).

The condition of the overall structure was fair to good. The most recent flood event had taken place April 18-19, 2013 and according to the report by WWE, portions of the terrace were completely flooded and the water surface had nearly reached the finished floor elevation. With the exception of water staining at the base of a wood door at the central core, little damage to the interior finishes was observed (although recent repairs have taken place according to the site staff) (*Figure C2*). The travertine panels at the exterior terrace were heaved to varying magnitudes and directions – presumably from either multiple flood events, or being subjected to multiple freeze/thaw cycles (*Figure C3*). The interior and exterior window stops at the floor level were rusted at multiple locations (*Figure C4*) which – as discussed on-site – were most likely a result of the connection detail exacerbated by occasional flood waters. The supporting elements of the stairs were corroded (*Figure C5*). One of the large plate-glass façade windows in the southeastern corner of the house was removed and replaced with plywood since it was broken during a recent storm (*Figure C6*). As discussed by the site staff, this was a result of initial cracks that had formed from previous flooding of the house itself which had increased in size and scope after a period of time.

The site staff also acknowledged that the terrace drainage no longer functions properly, and significant calcium buildup was observed at the drains on the underside of the deck (*Figure C7*). Peeling paint at the stairs, window stops, and other locations on the structure were observed along with evidence of roof leaks.

The site staff provided their best estimate based upon memory of the highest elevation historical flood waters had reached, and identified a location that was roughly near a set of rocks about 300 feet to the north of the house on the hill. The exact elevation of this location is not known but it is reasonable to assume that it correlates to a grade elevation near 574.0 ft. which is about 9 feet above the current finish grade elevation of the house at 564.75 ft.
Figure C1: Photograph from inside the house looking at the Fox River

Figure C2: Photograph interior of house, notice water staining at door base
Figure C3: Photograph showing cracked / heaved travertine panels at terrace

Figure C4: Photograph showing rust at facade glass frame
Figure C5: Photograph showing rust at main stair

Figure C6: Photograph showing exterior glass window broken at corner
Figure C7: Photograph showing mineral buildup at floor drains
Appendix D: Calculations
- Assume Exposure C
- V = 90
- I = 1.0
- λ₂ = 0.9 @ 20°
- λ₂ = 1.0
- λ₂ = 0.75
- GCPₖ = 7/₄ 0.18
- GCP₈ =
  - Face 1" 4 0.4 + 0.29 = 0.69
  - Face 5" 2.0 0.85

pₐₜ = 0.00256 (λₖ)(λₖ)(λₖ)(10') / 16

P = pₐₜ [(GCPₖ) - (GCP₈)]

W = 16(0.4 + 0.18) = 7.3
L = 16(0.02 + 0.18) = 7.5
G = 16(0.05 + 0.18) = 10.1

GROSS EA WALL

NET: 16 (0.4 + 0.29) = 11.0 PSF
Seismic Design - Base Shear - Existing Condition

\[ S_s := 0.163 \]  Figure 22-1, ASCE
\[ S_1 := 0.068 \]  Figure 22-2, ASCE
\[ MCE_g := 0.08 \]  Figure 22-7, ASCE

Class E, based upon soft clay soil

\[ F_a := 2.5 \]  Site Coefficient, Table 11.4-1, ASCE
\[ F_v := 3.5 \]  Site Coefficient, Table 11.4-2, ASCE

\[ S_{MS} := F_a S_s = 0.408 \]  Spectral Response Parameter for Short Periods, Section 11.4.3, ASCE

\[ S_{M1} := F_v S_1 = 0.238 \]  Spectral Response Parameter for Period at 1sec, Section 11.4.3, ASCE

\[ S_{DS} := \frac{2}{3} S_{MS} = 0.272 \]  Design Earthquake Spectral Acceleration Parameter at Short Periods, Section 11.4.4, ASCE

\[ S_{D1} := \frac{2}{3} S_{M1} = 0.159 \]  Design Earthquake Spectral Acceleration Parameter for Period at 1sec, Section 11.4.4, ASCE

\[ C_1 := 0.028 \]  Approximate Period Parameter, Table 12.8-2, ASCE
\[ h_n := 16 \text{ ft} \]  Steel Structure Height
\[ x := 0.8 \]  Approximate Period Parameter, Table 12.8-2, ASCE

\[ T_a := C_1 h_n^x = 0.257 \]  Approximation of fundamental period of structure, Section 12.8.2.1, ASCE

\[ T_0 := \frac{2S_{D1}}{S_{DS}} = 0.117 \]

\[ T_c := \frac{S_{D1}}{S_{DS}} = 0.584 \]

\[ S_a := S_{DS} = 0.777 \]  Design Response Spectral Acceleration value. Figure 11.4-1. ASCE

\[ R := 3 \]  Response Modification Factor, Ordinary Composite Frames, Table 12.2-1, ASCE
\[ I := 1.0 \]

Importance Factor for Occupancy Category II, 11.5-1, ASCE

\[ C_s := \frac{SDS}{R/I} = 0.091 \]

Seismic Response Coefficient, Section 12.8-2, ASCE

\[ W_{\text{LW}} = 549\text{kip} \]

Lumped weight of the structure

\[ \gamma = C_s \cdot W = 49.715 \text{kip} \]

Seismic base shear, Section 12.6-1, ASCE

\[ W_1 := 180\text{kip} \]

Weight of structure attributed to terrace level

\[ W_2 := 285\text{kip} \]

Weight of structure attributed to main floor level

\[ W_3 := 65\text{kip} \]

Weight of structure attributed to roof level

\[ h_1 := 2.7\text{ft} \]

Height from base to terrace level

\[ h_2 := 5.2\text{ft} \]

Height from base to main floor level

\[ h_3 := 16\text{ft} \]

Height from base to roof level

\[ k := 1 \]

Exponent related to the structure period, period less than .5s, Section 12.8.3, ASCE

\[
C_{v1} := \frac{W_1 \cdot h_1^k}{W_1 \cdot h_1^k + W_2 \cdot h_2^k + W_3 \cdot h_3^k} = 0.148
\]

Vertical distribution factor, Terrace level, 12.0-12, ASCE

\[
C_{v2} := \frac{W_2 \cdot h_2^k}{W_1 \cdot h_1^k + W_2 \cdot h_2^k + W_3 \cdot h_3^k} = 0.446
\]

Vertical distribution factor, Main floor level, 12.8-12, ASCE

\[
C_{v3} := \frac{W_3 \cdot h_3^k}{W_1 \cdot h_1^k + W_2 \cdot h_2^k + W_3 \cdot h_3^k} = 0.406
\]

Vertical distribution factor, Roof level, 12.8-12, ASCE

\[ F_{x1} := C_{v1} \cdot V = 7.343 \text{kip} \]

Lateral seismic force induced at terrace level
\[ F_{x2} = C_{v2} \cdot V = 22,197 \text{ kip} \]

\[ F_{x3} = C_{v3} \cdot V = 20,175 \text{ kip} \]

Lateral seismic force induced at main floor level

Lateral seismic force induced at roof level
Seismic Design - Base Shear - Elevated 6.5 ft

Steel Structure Height

\[ h_{st} = 22.5 \text{ ft} \]

Approximation of fundamental period of structure, Section 12.6.2.1, ASCE

\[ T_I = C_t h_{st} = 0.338 \]

Lumped weight of the structure

\[ W = 549 \text{kip} \]

Seismic base shear, Section 12.8-1, ASCE

\[ V_c = C_o W = 49.715 \text{kip} \]

Weight of structure attributed to terrace level

\[ W_{ter} = 180 \text{kip} \]

Weight of structure attributed to main floor level

\[ W_{m} = 285 \text{kip} \]

Weight of structure attributed to roof level

\[ W_{r} = 85 \text{kip} \]

Height from base to terrace level

\[ h_{ter} = 9.25 \text{ ft} \]

Height from base to main floor level

\[ h_{m} = 11.25 \text{ ft} \]

Height from base to roof level

\[ h_{r} = 22.5 \text{ ft} \]

Vertical distribution factor, Terrace level, 12.8-12, ASCE

\[ C_{ter} = \frac{W_1 h_1}{W_1 h_1^k + W_2 h_2^k + W_3 h_3^k} = 0.245 \]

Vertical distribution factor, Main floor level, 12.8-12, ASCE

\[ C_{m} = \frac{W_2 h_2}{W_1 h_1^k + W_2 h_2^k + W_3 h_3^k} = 0.473 \]

Vertical distribution factor, Main floor level, 12.8-12, ASCE

\[ C_{r} = \frac{W_3 h_3}{W_1 h_1^k + W_2 h_2^k + W_3 h_3^k} = 0.282 \]

Lateral seismic force induced at terrace level

\[ F_{ter} = C_{v1} V = 12.202 \text{kip} \]

Lateral seismic force induced at main floor level

\[ F_{m} = C_{v2} V = 23.497 \text{kip} \]

Lateral seismic force induced at roof floor level

\[ F_{r} = C_{v3} V = 14.016 \text{kip} \]
Seismic Design - Base Shear - Elevated 9 ft

\[ h_{n} = 25 \text{ ft} \]  
Steel Structure Height

\[ T_{n} = C_{T} h_{n}^{k} = 0.368 \]  
Approximation of fundamental period of structure, Section 12.8.2.1, ASCE

\[ W_{L} = 549\text{kip} \]  
Lumped weight of the structure

\[ X_{n} = C_{S} W_{L} = 497.715\text{kip} \]  
Seismic base shear, Section 12.8.1, ASCE

\[ W_{1} = 180\text{kip} \]  
Weight of structure attributed to terrace level

\[ W_{2} = 285\text{kip} \]  
Weight of structure attributed to main floor level

\[ W_{3} = 85\text{kip} \]  
Weight of structure attributed to roof level

\[ h_{1} = 11.75 \text{ ft} \]  
Height from base to terrace level

\[ h_{2} = 14.25 \text{ ft} \]  
Height from base to main floor level

\[ h_{3} = 25 \text{ ft} \]  
Height from base to roof level

\[ C_{T} = \frac{W_{1} h_{1}^{k}}{W_{1} h_{1}^{k} + W_{2} h_{2}^{k} + W_{3} h_{3}^{k}} = 0.255 \]  
Vertical distribution factor, Terrace level, 12.8-12, ASCE

\[ C_{M} = \frac{W_{2} h_{2}^{k}}{W_{1} h_{1}^{k} + W_{2} h_{2}^{k} + W_{3} h_{3}^{k}} = 0.489 \]  
Vertical distribution factor, Main floor level, 12.8-12, ASCE

\[ C_{R} = \frac{W_{3} h_{3}^{k}}{W_{1} h_{1}^{k} + W_{2} h_{2}^{k} + W_{3} h_{3}^{k}} = 0.256 \]  
Vertical distribution factor, Roof level, 12.8-12, ASCE

\[ F_{1} = C_{V1} V = 12.666\text{kip} \]  
Lateral seismic force induced at terrace level

\[ F_{2} = C_{V2} V = 24.322\text{kip} \]  
Lateral seismic force induced at main floor level

\[ F_{3} = C_{V3} V = 12.726\text{kip} \]  
Lateral seismic force induced at roof floor level
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RISA-3D Version 8.1.2  [P:\L1\Projects\C13103.00\Analysis\Calculations\Farnsworth Existing.r3d]  Page 5
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Geometry, Materials and Criteria

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RISAFoot Version 3.0
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ALLOWABLE GROSS BEARING PRESSURE OF 3000 PSF IS EXCEEDED FOR THE LOAD CASES IDENTIFIED; THE ALLOWABLE BEARING PRESSURE IS ALSO EXCEEDED FOR THE LOAD CASES SHOWN HIGHLIGHTED WHEN THE GIVEN BEARING PRESSURE IS ASSUMED TO BE THE ALLOWABLE NET BEARING PRESSURE.
- No Design Calculations Due to Soil Bearing Failure -
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Sketch

Geometry, Materials and Criteria

- Length: 6 ft
- Width: 6 ft
- Thickness: 15 in
- Height: 28 in
- Gross Allow. Bearing: 3000 psf (gross)
- Concrete Weight: 145 pcf
- Concrete fc: 3 ksi
- Steel fy: 33 ksi
- Minimum Steel: 0.0018
- Maximum Steel: 0.0075
- Design Code: ACI 318-05

- Footing Top Bar Cover: 3.5 in
- Footing Bottom Bar Cover: 3.6 in
- Overturning Safety Factor: 1.5
- Coefficient of Friction: 0.6
- Phi for Flexure: 0.9
- Phi for Shear: 0.75
- Phi for Bearing: 0.65

Passive Resistance of Soil: 0 k

Loads

<table>
<thead>
<tr>
<th>P (k)</th>
<th>Vx (k)</th>
<th>Vz (k)</th>
<th>Mx (k-ft)</th>
<th>Mz (k-ft)</th>
<th>Overburden (psf)</th>
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<tr>
<td>DL</td>
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RISAFoot Version 3.0
## Soil Bearing

<table>
<thead>
<tr>
<th>Description</th>
<th>Categories and Factors</th>
<th>Gross Allow (psf)</th>
<th>Max Bearing (psf)</th>
<th>Max/Allowable Ratio</th>
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<td>3604.72 (C)</td>
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ALLOWABLE GROSS BEARING PRESSURE OF 3000 PSF IS EXCEEDED FOR THE LOAD CASES IDENTIFIED. THE ALLOWABLE BEARING PRESSURE IS ALSO EXCEEDED FOR THE LOAD CASES SHOWN HIGHLIGHTED WHEN THE GIVEN BEARING PRESSURE IS ASSUMED TO BE THE ALLOWABLE NET BEARING PRESSURE.
**APPENDIX D: Page 20 of 31**

- No Design Calculations Due to Soil Bearing Failure -
CHECK CHANNEL CONN TO COLUMN

COL: W6x48  d = 8.5  b = 8.1
CHANNEL C: 15 x 60  d = 15

Y

CALC WELD PROPS

b = 7
d = 15

\[ S_x = b d = 7 \times 15 = 105 \text{ in}^2 \]
\[ S_y = b^2 / 3 = 7^2 / 3 = 114.3 \text{ in}^2 \]
\[ J_y = b^3 + 3bd^2 = 7^3 + 3(7 \times 15)^2 = 845 \text{ in}^2 \]

check
\[ J_y = b (3b^2 + b^2) / 6 = 7 (3(15)^2 + 7^2) = 845 \text{ in}^2 \]
CONNECTION LOAD PATH ASSUMPTIONS:

- Moments about 'X' axis are resisted by the flange plate that passes through the channel at the top of the inframing WR and through bearing at the bottom where the flange of the WR & C15 are aligned.

- Moments about the 'Y' axis are resisted by the 3/8" groove welds at the top and bottom of the channel.

- Shear loads on the XE plane are resisted by the welds at the top and bottom of the channel.

- Axial loads in the 'Y' direction are resisted by the same elements as those resisting moments about the 'X' axis.

- Plug welds are ignored.

- See details from drawings on next page.
AS-BUILT CONDITION

DL  \( P_E = 6.3 - 15.7 = 47.3 \)
    \( P_X = 0.9 - 0 = 0.9 \)
    \( P_Y = 4.9 - 2.4 = 5.5 \)
    \( M_X = 44.4 \)
    \( M_Y = 85.1 - 81.2 = 3.9 \)

LL  \( P_E = 13.4 \)
    \( P_X = 0.3 - 0 = 0.3 \)
    \( P_Y = 2.5 - 0.4 = 2.1 \)
    \( M_X = 13.3 \)
    \( M_Y = 24.6 \) (UNBALANCED)

WLX  \( P_E = 0 \)
    \( P_X = 0.4 - 0.3 = 0.1 \)
    \( P_Y = 0 \)
    \( M_X = 0.1 \)
    \( M_Y = 1.2 + 1 = 2.2 \)

WLY  \( P_E = -0.5 - (0.2) = -0.3 \)
    \( P_X = 0.0 \)
    \( P_Y = 1.0 - 0.4 = 0.6 \)
    \( M_X = 3.7 \)
    \( M_Y = 0.2 + 0.3 = 0.5 \)
\[ \begin{align*}
\text{ELX} & \quad P_E = 0.8 - 0.5 = 0.3 \\
& \quad P_X = 4.3 - 2.7 = 1.6 \\
& \quad P_Y = 0.4 - 0 = 0.4 \\
& \quad M_X = 0.7 \\
& \quad M_Y = 15.1 + 10.6 = 25.7 \\
\text{ELY} & \quad R_E = 2.2 - 1.0 = 1.2 \\
& \quad R_X = 0.0 \\
& \quad R_Y = 4.1 - 2 = 2.1 \\
& \quad M_X = 13.2 \\
& \quad M_Y = 0
\end{align*} \]
LOAD COMBINATIONS

(1) 1.2D + 1.6L

\[ P_x = 1.2(47.3) + 1.6(13.4) = 78.2 \]
\[ P_y = 1.2(0.9) + 1.6(0.3) = 1.6 \]
\[ P_v = 1.2(5.5) + 1.6(2.1) = 10.0 \]

\[ M_x = 1.2(44.4) + 1.6(13.3) = 74.6 \]
\[ M_y = 1.2(3.9) + 1.6(24.6) = 44.0 \]

(2) 1.2D + 1.0L + 1.6WLx

\[ P_x = 1.2(47.3) + 1.0(13.4) + 1.6(0.0) = 70.7 \]
\[ P_y = 1.2(0.9) + 1.6(0.3) + 1.6(0.1) = 1.3 \]
\[ P_v = 1.2(5.5) + 1.0(2.1) + 1.6(0) = 8.7 \]

\[ M_x = 1.2(44.4) + 1.0(13.3) + 1.6(0.1) = 66.7 \]
\[ M_y = 1.2(3.9) + 1.0(4.6) + 1.6(2.2) = 32.8 \]

(3) 1.2D + 1.0L + 1.6WLy

\[ P_x = 1.2(47.2) + 1.0(13.4) + 1.6(0.3) = 70.6 \]
\[ P_y = 1.2(0.9) + 1.0(0.3) + 1.6(0) = 1.4 \]
\[ P_v = 1.2(5.5) + 1.0(2.1) + 1.6(0.8) = 9.7 \]

\[ M_x = 1.2(44.4) + 1.0(13.3) + 1.6(3.2) = 72.5 \]
\[ M_y = 1.2(3.9) + 1.0(24.6) + 1.6(0.5) = 30.1 \]
\[(4)\] \[1.2D + 1.0L + 1.0ELX\]

\[
P_x = 1.2(4.73) + 1.0(13.4) + 1.0(0.3) = 70.5
\]

\[
P_y = 1.2(0.9) + 1.0(0.3) + 1.0(1.6) = 3.0
\]

\[
R_y = 1.2(5.5) + 1.0(2.1) + 1.0(0.9) = 9.1
\]

\[
M_x = 1.2(44.4) + 1.0(13.3) + 1.0(0.7) = 67.3
\]

\[
M_y = 1.2(3.9) + 1.0(74.6) + 1.0(25.7) = 55.0
\]

\[(5)\] \[1.2D + 1.0L + 1.0ELY\]

\[
P_x = 1.2(4.73) + 1.0(13.4) + 1.0(1.2) = 71.4
\]

\[
P_y = 1.2(0.9) + 1.0(0.3) + 1.0(0) = 1.4
\]

\[
R_y = 1.2(5.5) + 1.0(2.1) + 1.0(2.1) = 11.6
\]

\[
M_x = 1.2(44.4) + 1.0(13.3) + 1.0(13.2) = 84.8
\]

\[
M_y = 1.2(3.9) + 1.0(24.6) + 1.0(0) = 29.3
\]
CHECK GROOVE WELD AT TOP & BOTTOM OF C15 CHANNEL

\[
LC1 \sqrt{(78.2/14)^2 + (1.6/14 + \frac{44 \times 12 \times 0.75}{845})^2} = 7.4 \text{ k/l/in}
\]

\[
LC4 \sqrt{(70.3/14)^2 + (3/14 + \frac{53 \times 12 \times 0.75}{845})^2} = 7.7 \text{ k/l/in}
\]

IF WELDS ARE TREATED AS FILLET WELDS; CAPACITY = 7.2 k/l/in
IF TREATED AS A GROOVE WELD; BASE METAL GOU'S:

\[
\frac{3}{8} \times 1'' \times 33 \text{ ksi} \times 0.9 = 11.1 \text{ k/l/in} \quad \text{OK}
\]

\[
\frac{3}{8} \times 1'' \times 60 \times 0.75 = 16.9 \text{ k/l/in} \quad \text{OK}
\]

CHECK GROOVE WELD AT PLATE PASSING THROUGH CHANNEL & GROOVE WELDED TO COLUMN

WORST CASE IS LC5; MX = 84.8 & PY = 116

\[
\frac{84.8 \times 12}{12} + \frac{11.6}{2} = 90.6 \text{ k}
\]

CJP SHOWN: BASE METAL GOU'S

\[
6 \times \frac{1}{2} \times 33 \times 0.9 = 89.1 \approx 90.6 \text{ k} \quad \text{OK}
\]

\[
6 \times \frac{1}{2} \times 60 \times 0.75 = 135 \quad \text{OK}
\]

CHECK 'C' SHAPE WELD ON FLANGE CONNECT

\[
6'' \quad \text{Total Weld = 18''}
\]

\[
1.19 \times 18 \times 5 = 107.1 \geq 90.6 \quad \text{OK}
\]
Repeat calcs for raised condition (90°)

**DL**
\[ P_x = 64 - 15.7 = 48.3 \]
\[ P_y = 0.7 \]
\[ R_y = 3.5 - 2 = 1.5 \]
\[ M_x = 41 \]
\[ M_y = 86.6 - 83.5 = 3.1 \]

**LL**
\[ P_x = 13.6 \]
\[ P_y = 0 \]
\[ R_y = 0.7 - 0.5 = 0.2 \]
\[ M_x = 12.4 \]
\[ M_y = 25.1 \text{ (unbalanced)} \]

**ELY**
\[ P_x = 3.0 - 0.8 = 2.2 \]
\[ P_y = 0 \]
\[ R_y = 4.6 - 1.1 = 3.5 \]
\[ M_x = 32.5 \]
\[ M_y = 0 \]
\[ Lc1 \quad 1.2D + 1.6L \]

\[ P_e = 79.7 \]
\[ P_x = 0.7 \]
\[ P_y = 2.1 \]
\[ M_x = 69 \]
\[ M_y = 93.9 \]

\[ Lc4 \quad 1.2D + 1.0L + 1.0ELx \]

\[ P_e = 75 \]
\[ P_x = 2.8 \]
\[ P_y = 2.0 \]
\[ M_x = 62.2 \]
\[ M_y = 67.4 \]

\[ Lc5 \quad 1.2D + 1.0L + 1.0ELY \]

\[ P_e = 73.8 \]
\[ P_x = 0.7 \]
\[ P_y = 5.5 \]
\[ M_x = 94.1 \]
\[ M_y = 28.8 \]
CHECK GROOVE WELD AT TOP & BOTTOM OF CHANNEL

\[ LCI \sqrt{\left(\frac{79.7/1.1}{14} \right)^2 + \left(0.2/14 + \frac{8.9 \times 12 \times 7.5}{895}\right)^2} = 7.4 \text{ k}\]

\[ LC4 \sqrt{\left(\frac{73.8/1.1}{14} \right)^2 + \left(0.2/14 + \frac{28.8 \times 12 \times 7.5}{895}\right)^2} = 6.1 \text{ k}\]

SAME OR LESS THAN PREVIOUS

CHECK GROOVE WELD AT PLATE PASSING THROUGH:

WORST CASE IS LC5; \( Mx = 94.1 \) & \( Py = 5.5 \)

\[ \frac{94.1 \times 12}{12} + 5.5/2 = 96.9 \text{ k} \]

\( \Rightarrow \) RESULTS IN APPROX 9% OVER CAPACITY
MAY REQ REINFORCED OR MORE EXTENSIVE ANALYSIS TO PROVE UP

"S" GROOVE WELD STILL OK