

IES-NUS Design for Safety (DfS) Library for Designers:

Construction and Maintenance Design Risks

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Disclaimer

1. The information presented below is for consideration only. This document is not an official Design for Safety (DfS) guide – readers must consider their actual needs, which may vary across projects.
2. Ultimately, the Designers need to assimilate this information with their experience and skills to develop their approach.
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Introduction

This DfS Library aims to assist designers in improving the comprehensiveness of their DfS review process by providing examples of construction and maintenance-related design considerations, design risks, and possible design changes and design-related controls. It is noted that as part of the DfS review process, the designers will have to consult with various stakeholders to ensure that the design changes and design-related controls are practicable and effective.

DfS Examples

Precast and Prefabrication Elements

Category A: Precast and Prefabrication Elements	
S/N:	A-1
Design Consideration:	Large and heavy prefabricated beams and columns that need to be lifted in place
Context:	The structure under construction is in the vicinity of sensitive structures (MRT/LRT viaduct). The site also has constraints that require the crane to be sited far from the structure where the prefabricated beam and columns must be installed. Thus, even the larger cranes need to operate at 95%-110% of the safe working load (SWL).
Design Risk:	The presence of large and heavy precast beams and columns in the design that need to be lifted and installed in the vicinity of sensitive structures and the lifting radius is large. These design risks increase the likelihood of crane overload during construction.
Possible Incident:	Workers struck by falling objects caused by inadequate crane load capacity.
Possible Design-Related Control(s) or Change(s):	Substitution <ol style="list-style-type: none"> 1. Use U-shaped precast beams with cast-in-situ infill concrete to reduce the crane load (see Figure 1). 2. Use precast shell columns with cast-in-situ infill concrete to reduce the crane load (see Figure 2). 3. Considering the proximity to the sensitive structures, change selected precast elements to cast-in-situ to mitigate crane overload issues.

	Note: Precast elements have obvious benefits in terms of speed and safety, but in this case, a partially cast-in-situ solution is selected because of the high risk of crane collapse.
Action By:	C&S Engineer, Architect

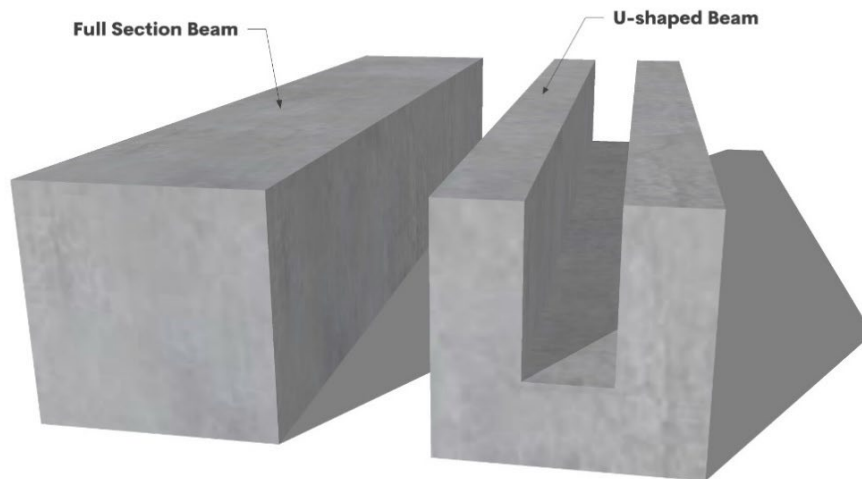


Figure 1 Use u-shaped precast beams instead of full section beam

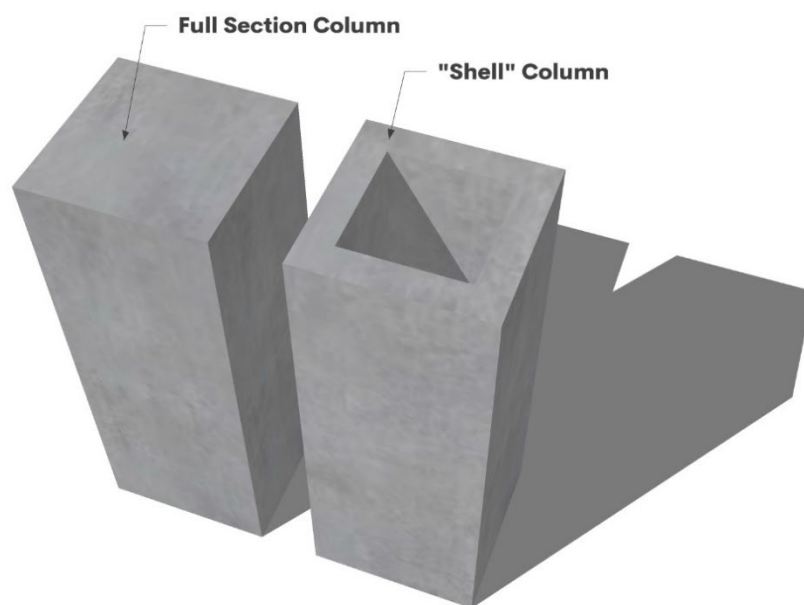
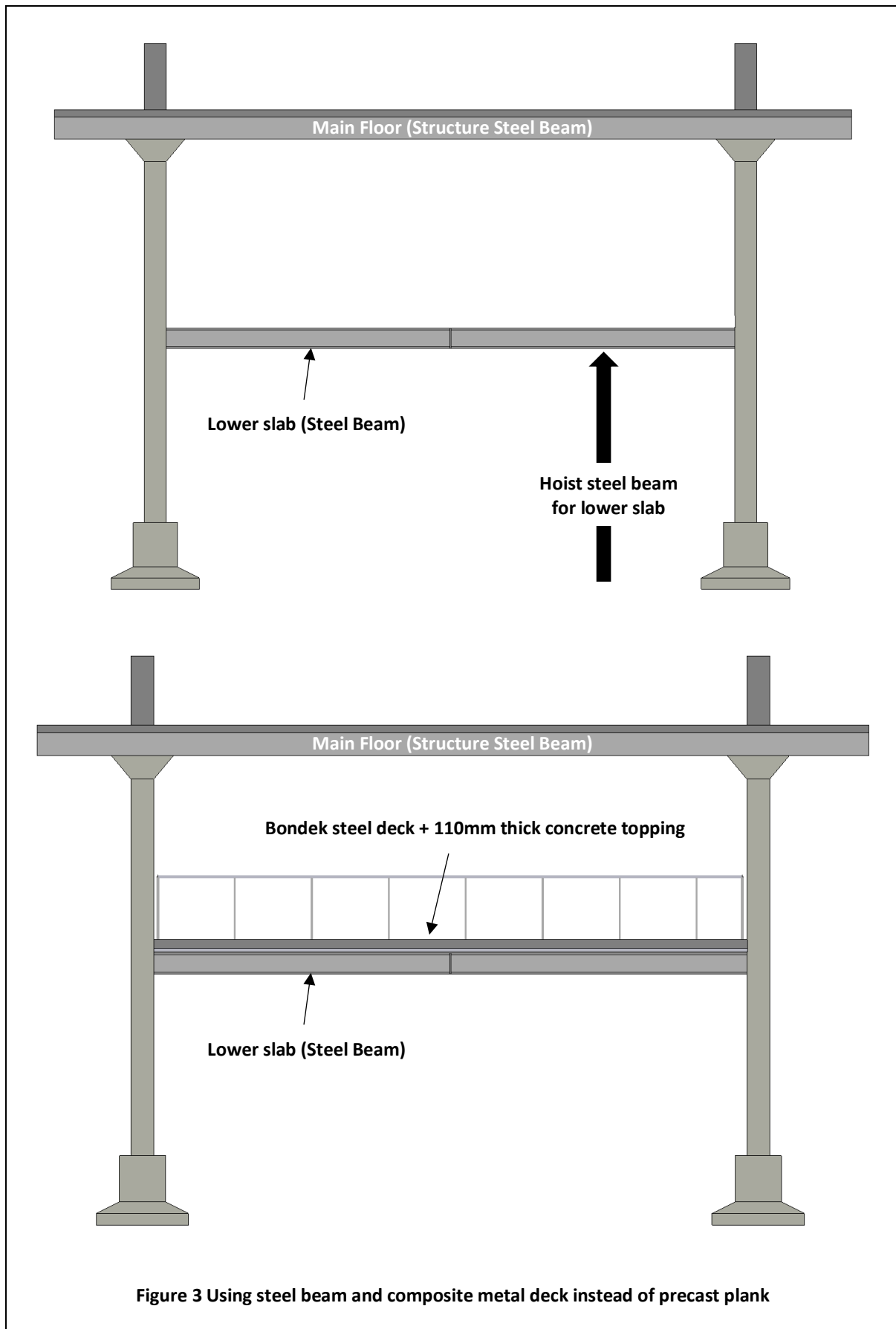



Figure 2 Use shell precast columns instead of full section column

Category A: Precast and Prefabrication Elements	
S/N:	A-2
Design Consideration:	Lower slab made of steel sections and precast planks; slab is below the main floor of a building
Context:	The main floor (see Figure 3) must be constructed first to ensure structural stability during construction. Thus, during the construction of the lower slab (not part of the main structural frame), there is not enough headroom to use a crane to lift the precast planks safely. Therefore, the workers need to handle the heavy precast planks manually.
Design Risk:	The presence of the main floor during the installation of the lower slab prevents cranes from lifting the precast planks, leading to manual handling of the planks, which increases the likelihood of bodily injuries.
Possible Incident:	<ol style="list-style-type: none"> 1. Musculoskeletal injuries during manual handling of planks; 2. Workers struck by falling precast planks.
Possible Design-Related Control(s) or Change(s):	Substitution Revise the design to replace the precast plank with steel section with composite metal decks, which are lighter and safer to handle; see Figure 3 for the construction sequence.
Action By:	C&S Engineer



Category A: Precast and Prefabrication Elements	
S/N:	A-3
Design Consideration:	Heavy precast components and vehicular access in construction sites
Context:	The project uses heavy precast components, which require large mobile cranes to be used on-site; the site has poor soil conditions.
Design Risk:	The presence of heavy precast components leads to large mobile cranes on vehicular access way, which increases the likelihood of access way failure and crane toppling (especially during lifting).
Possible Incident:	The toppling of heavy cranes on site vehicular access way.
Possible Design-Related Control(s) or Change(s):	Engineering Control <ol style="list-style-type: none"> 1. Design the vehicular access way based on conservative estimates of the loading imposed by the heavy cranes during lifting and access. 2. Improve soil conditions with appropriate use of compaction and hardcore. When necessary and for high-risk locations, techniques such as jet grouting, i.e., cutting the ground with high-pressure jet, mixing, and replacing the slurry with cement grout, should be implemented according to BS EN 12716. 3. Steel plates can distribute the vehicular load, but the steel plates will need to be designed to prevent deformation. In addition, the steel plates should be designed to prevent accidental movement and have sufficient friction to prevent vehicles from slipping.
Action By:	C&S Engineer

Category A: Precast and Prefabrication Elements	
S/N:	A-4
Design Consideration:	Prefabricated link bridge
Context:	A prefabricated link bridge to be installed between two towers using welding (see Figure 4); temporary corbels are provided. Due to the position of the joints, the welding is expected to take significant time.
Design Risk:	The presence of the joints between the link bridge and the towers requires workers to work at height when welding the joints, and the extended exposure increases the likelihood of workers falling from height.
Possible Incident:	Workers fall from height due to the need to work at height for an extended period.
Possible Design-Related Control(s) or Change(s):	Substitution Design the connection between the bridge and the towers to use bolting instead of welding.
Action By:	Architect, C&S Engineer
 <p>Figure 4 Worker welding the joints of the prefabricated link bridge to the main tower</p>	

Temporary Works

Category B: Temporary Works	
S/N:	B-1
Design Consideration:	Glass panel underneath link bridge
Context:	Two towers with a link bridge in-between; the towers and link bridge have glass façade. During construction, hanging scaffolds are used to install the glass panels below the link bridge.
Design Risk:	The presence of glass panels underneath the link bridge requires hanging scaffolds during construction, which increases the likelihood of workers falling from height and being struck by a falling object during construction.
Possible Incident:	Workers fall from height while erecting or working on the hanging scaffold; the collapse of hanging scaffold.
Possible Design-Related Control(s) or Change(s):	<p>Elimination Change the glass panels underneath the link bridge to aluminium panels and pre-install the panels before lifting the link bridge.</p> <p>Substitution</p> <ol style="list-style-type: none"> 1. Use boom lift or other mobile elevating work platforms (MEWPs). Designers need to check that the ground designated for the location of the MEWPs can take the loading of the MEWPs, is within the allowed operating slope angle of the MEWPs, and within reach of the MEWPs (see Figure 5). 2. If possible, design the panels to be installed from within the link bridge. 3. Pre-install the Building Maintenance Unit (BMU) track below the link bridge before lifting or jacking the link bridge into position (see Figure 6). After the bridge installation, the BMU can be installed onto the track using the wall openings below the bridge. Once the BMU is installed, it can be used to install the glass panels.
Action By:	C&S Engineer or Architect



Figure 5 Designate a safe location for the MEWPs

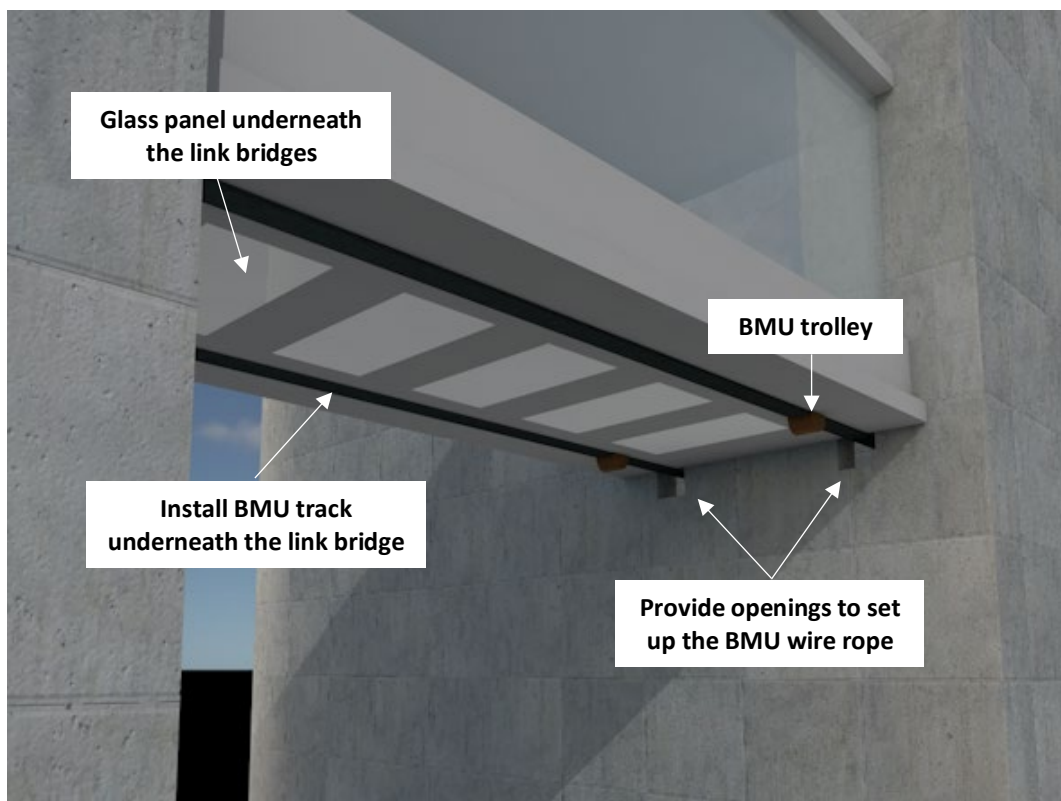


Figure 6 Installing gondola rail on link bridge before lifting to position

Category B: Temporary Works	
S/N:	B-2
Design Consideration:	King post (13m – 16m long per segment)
Context:	Top-down construction for a deep basement where the king posts are joined using welding. The longer segments are heavier than normal king post segments.
Design Risk:	The presence of long king post segments requires welding, which takes some time to be completed—the time taken to weld the segments represent increased exposure to the risk of king post or piling machine collapse.
Possible Incident:	The collapse of king posts or piling machines during construction.
Possible Design-Related Control(s) or Change(s):	Substitution Substitute welding of king post joints with bolting (i.e., splice joint) designed according to SS EN 1993-1-8 (see Figure 7) to minimise the risk of king posts or piling machine collapse.
Action By:	C&S Engineer

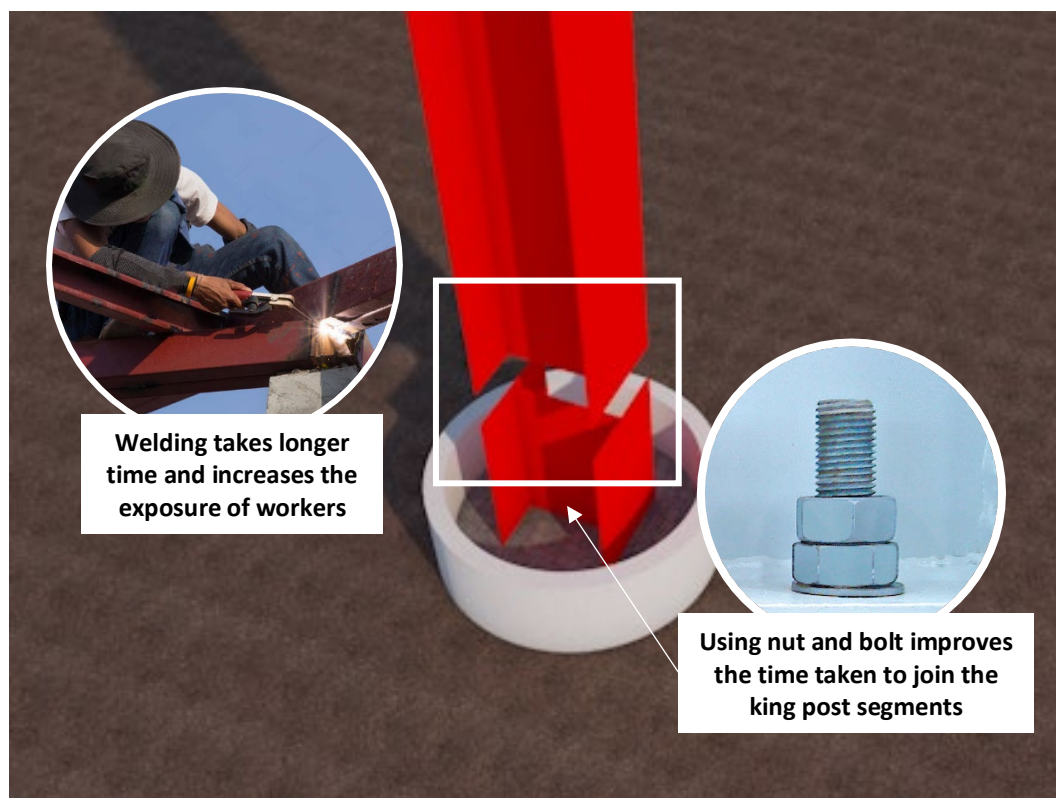

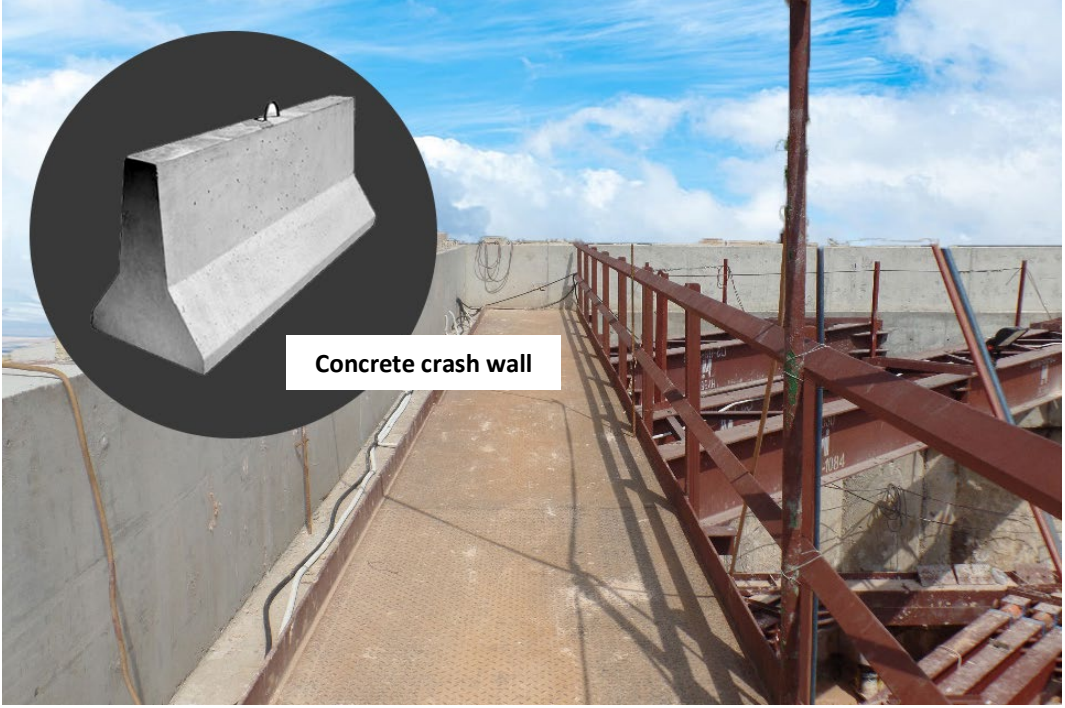


Figure 7 Using nut and bolt instead of welding

Category B: Temporary Works	
S/N:	B-3
Design Consideration:	Basement
Context:	Basement construction for a low-rise residential structure using an open cut with a slope; the site has nearby high-rise structures. It was identified that there is a lack of consideration of the most severe situation in terms of design parameters (e.g., soil parameters and loading conditions).
Design Risk:	The presence of nearby high-rise structures increases the likelihood of Earth Retaining Stabilising Structure (ERSS) failure during construction. The failure increases the likelihood of excessive or differential ground settlement (i.e., tilting of nearby structures) or damage to underground services. The ERSS failure can also lead to structural collapse.
Possible Incident:	Failure of ERSS leads to damages to nearby structures, structural collapse and related accidents.
Possible Design-Related Control(s) or Change(s):	Engineering Control <ol style="list-style-type: none"> 1. Soil parameters should consider the most severe situation (e.g., excessive rain). 2. Design must cater for loading conditions due to over-excavation.
Action By:	C&S Engineer
<p style="text-align: center;">Reference:</p> <p style="text-align: center;">Earth Slip at Excavation Site Case Study (by Building and Construction Authority) [You may read the case here¹]</p>	

¹ https://www1.bca.gov.sg/docs/default-source/docs-corp-regulatory/building-control/lessons-learnt-from-structural-failures/earth-slip-at-excavation-site.pdf?sfvrsn=125708cb_2

Category B: Temporary Works	
S/N:	B-4
Design Consideration:	Precast staircases
Context:	Precast staircases are used on a residential building construction site. Once the precast staircases are installed, workers need to install guardrails along the open edges of the staircases.
Design Risk:	The presence of open edges on the staircases increases the likelihood of falling from height or being struck by a falling object during construction.
Possible Incident:	Workers fall from height or struck by falling object due to the presence of open edges after staircases are installed.
Possible Design-Related Control(s) or Change(s):	<p>Elimination Design for precast staircases with guardrails or railings pre-installed onto the staircases before being lifted into place (see Figure 8).</p> <p>Substitution Make provisions for brackets for faster and easier installation of railings after the precast stairs are installed.</p>
Action By:	C&S Engineer
	
<p>Figure 8 Guardrails and railings pre-installed onto the precast staircase</p>	

Category B: Temporary Works	
S/N:	B-5
Design Consideration:	Large temporary ground-level openings for the lifting of materials or equipment to the basement
Context:	The temporary ground-level openings are near site traffic access routes; the openings are protected with temporary guardrails meant to prevent workers from falling from height.
Design Risk:	The presence of temporary access openings at ground level increases the likelihood of vehicles and plants falling into the openings.
Possible Incident:	Vehicles or plants might crash into the guardrails and fall through, causing serious injuries or death during construction.
Possible Design-Related Control(s) or Change(s):	<p>Substitution Locate the openings away from vehicle access routes to reduce the likelihood of vehicles and plants near the openings.</p> <p>Engineering Control Design a temporary crash wall at the perimeter of the openings to prevent vehicles or equipment from crashing through (see Figure 9).</p>
Action By:	C&S Engineer
 <p>The image shows a construction site with a concrete crash wall. A circular inset in the top left corner provides a close-up view of the concrete wall, which has a T-shaped cross-section. The main image shows the wall installed around the perimeter of a basement opening, with a metal railing and scaffolding visible in the background.</p>	
<p>Figure 9 Design for a temporary concrete crash wall around the perimeter of the basement</p>	

Category B: Temporary Works	
S/N:	B-6
Design Consideration:	Thick transfer slab
Context:	C&S engineer has proposed a 2m thick transfer slab (at the height of 9m) to be cast monolithically (single layer), creating a need for a massive falsework to support the 2m wet concrete (around 5t/m ²) during casting (see Figure 10).
Design Risk:	The presence of a thick monolithic cast-in-situ transfer slab increases the likelihood of structural collapse during casting.
Possible Incident:	The collapse of formwork during the casting of thick transfer slab.
Possible Design-Related Control(s) or Change(s):	<p>Engineering Control</p> <p>Design the transfer slab to be cast in two layers to reduce wet concrete loading to the falseworks—design falseworks to support first layer concrete with a thickness of about 800mm. Once the first layer of concrete gains the design strength, it will support the second layer of concrete.</p>
Action By:	<p>C&S Engineer, Architects</p> <p>Note: Architects should involve specialist falsework designers at the concept or detailed design stages to address such design risks.</p>



Figure 10 Using heavy-duty falsework system to support the single thick layer cast-in-situ transfer slab

Roof and Skylight

Category C: Roof and Skylight	
S/N:	C-1
Design Consideration:	Fragile and transparent skylight
Context:	A building with a skylight.
Design Risk:	The presence of fragile and transparent material on the roof increases the likelihood of falling from height.
Possible Incident:	Workers fall from height caused by stepping onto the fragile skylight material or space created during installation, repair, or skylight removal.
Possible Design-Related Control(s) or Change(s):	<p>Elimination/ Substitution Design the skylight to allow workers to do most or all skylight installation and maintenance work inside the building.</p> <p>Substitution The strength of the skylight material must be assessed as part of the design process; fragile or non-load bearing skylight can be substituted with material that can withstand appropriate installation or maintenance loading.</p> <p>Engineering Control</p> <ol style="list-style-type: none"> 1. Specify or design for a load-bearing mesh cover (no more than 50mm grid) that is resistant to corrosion and ultraviolet (UV) rays over the fragile skylight without compromising the amount of light passing through (see Figure 11). 2. Design a location at the ground level or below the skylight to park MEWPs so that workers can work within the MEWP basket to minimise the need to stand on the roof itself. 3. Design for permanent or temporary maintenance access platform over fragile roof as far as possible. <p>Administrative Control Specify glass panels to have removable stickers (see Figure 12) to make them more noticeable during construction.</p> <p>Personal Protective Equipment (PPE) Design and position fall protection systems (travel restraint systems or fall arrest systems) for workers.</p>

	Note: So far as is reasonably practicable, collective protective measures must be used instead of individual protective measures (e.g., PPE).
Action By:	C&S Engineer, Architect
	
Figure 11 Adding a load-bearing mesh cover over the skylight	
	
Figure 12 Removable stickers on the clear glass panels	

Category C: Roof and Skylight	
S/N:	C-2
Design Consideration:	Link bridge between buildings (see Figure 13)
Context:	Link bridge between buildings with roof that requires workers to work-at-height during construction and maintenance.
Design Risk:	The presence of a link bridge roof with open edges increases the likelihood of workers falling from height.
Possible Incident:	Workers fall from height during the installation or maintenance of the link bridge.
Possible Design-Related Control(s) or Change(s):	<p>Elimination (for construction work) Design for a link bridge that can be assembled on-site and installed without requiring workers to be on the roof of the link bridge.</p> <p>Engineering Control Design for edge protection on the roof of the link bridge pre-installed before the bridge is lifted into place.</p> <p>Personal Protective Equipment (PPE) Design for permanent fall protection systems (travel restraint or fall arrest system) pre-installed before the link bridge is lifted into place (see Figure 14).</p> <p>Note: So far as is reasonably practicable, collective protective measures must be used instead of individual protective measures (e.g., PPE).</p>
Action By:	Architect, C&S engineer

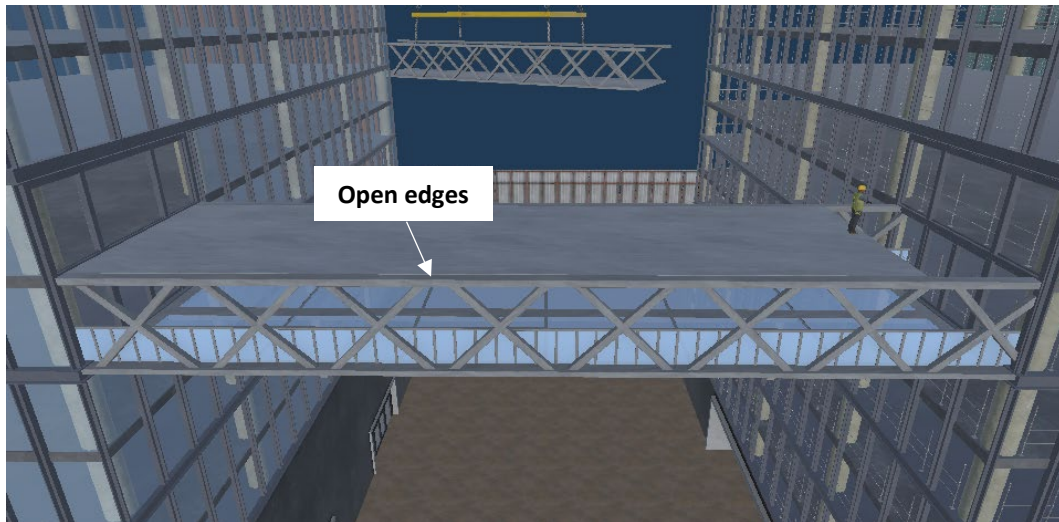


Figure 13 Open edges on the roof of the link bridge



Figure 14 Design for fall protection systems that are pre-installed before link bridge is lifted into place

Category C: Roof and Skylight	
S/N:	C-3
Design Consideration:	Green roof without parapet wall
Context:	The green roof is designed with no parapet wall or guardrails; green features need to be at the edge of the building for aesthetic reasons.
Design Risk:	The presence of open edges increases the likelihood of workers falling from height during construction and maintenance.
Possible Incident:	Workers fall off the open edges during construction or maintenance.
Possible Design-Related Control(s) or Change(s):	<p>Substitution (for maintenance work) Minimise the need for maintenance by providing an auto-irrigation system (see Figure 15) or plants that do not require frequent pruning or replacement.</p> <p>Engineering Control Design edge protection (guardrails and toe boards) along the roof and install it as early as possible (see Figure 16). The edge protection should be designed to prevent climbing where toes and feet cannot be slotted into the edge protection. This requirement may be less stringent for areas with maintenance access only.</p> <p>Personal Protection Equipment (PPE) Design for fall protection systems (travel restraint or fall arrest system) installed as early as possible.</p> <p>Note: So far as is reasonably practicable, collective protective measures must be used instead of individual protective measures (e.g., PPE).</p>
Action By:	Architect

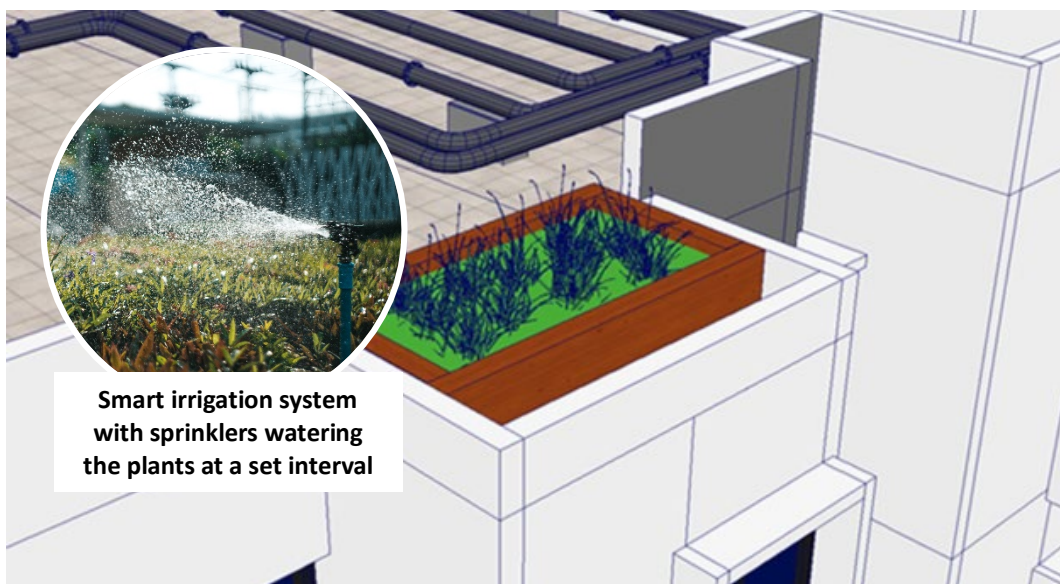


Figure 15 Auto-irrigation system

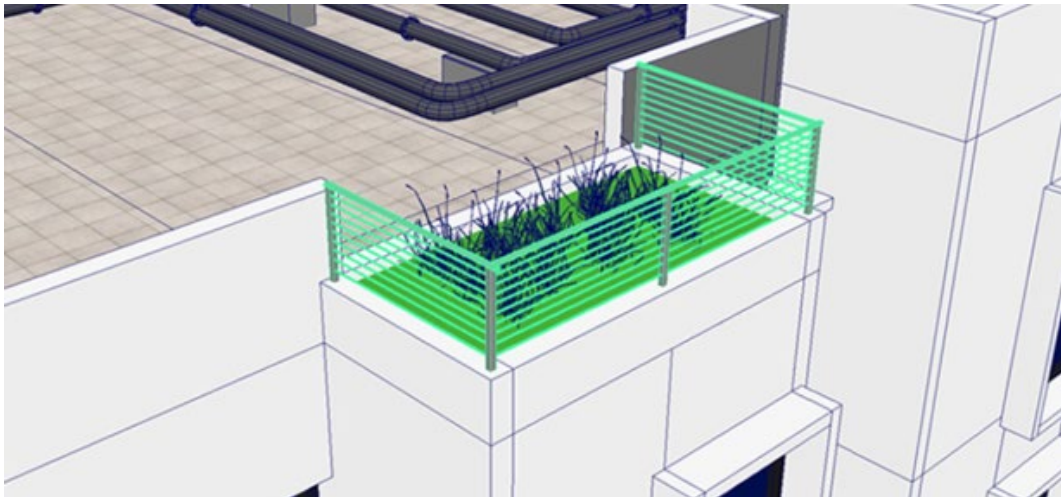


Figure 16 Design for edge protection like guardrails and toe boards as early as possible (edge protection should be designed to prevent climbing if the area is for public access)

Category C: Roof and Skylight	
S/N:	C-4
Design Consideration:	Photo-voltaic (PV) panels on the roof of buildings
Context:	A roof with PV panels and no parapet wall or edge protection. Designers placed the PV panels close to the edges because they did not consider fire safety requirements for the PV panels. The issue was highlighted during the DfS review.
Design Risk:	<ol style="list-style-type: none"> 1. The presence of unprotected open edges increases the likelihood of workers falling from height during the construction and maintenance of PV panels. 2. The presence of PV panels on the roof is a fire hazard. If it is not properly designed, installed, or maintained, it can increase the likelihood of fire on the roof.
Possible Incident:	<ol style="list-style-type: none"> 1. Workers fall off the open edges. 2. Fire incident related to the non-compliant location of the PV panels, the width of aisles, etc.
Possible Design-Related Control(s) or Change(s):	<p>Engineering Control</p> <ol style="list-style-type: none"> 1. Design for parapet or edge protection along the roof and install it as early as possible (see Figure 17). 2. Design the location of the PV panels, the width of aisles, etc. based on the Fire Code (see Figure 18): https://www.scdf.gov.sg/firecode/table-of-content/chapter-10-requirements-for-special-installations/clause-10.2. Compliance with the Fire Code will also ensure that the PV panels are away from the roof edges to minimise workers' exposure to fall from height hazards. <p>Personal Protection Equipment (PPE) If parapets or edge protections are not installed, design for fall protection systems (travel restraint or fall arrest system) installed as early as possible.</p> <p>Note: So far as is reasonably practicable, collective protective measures must be used instead of individual protective measures (e.g., PPE).</p>
Action By:	Architect, M&E Engineer

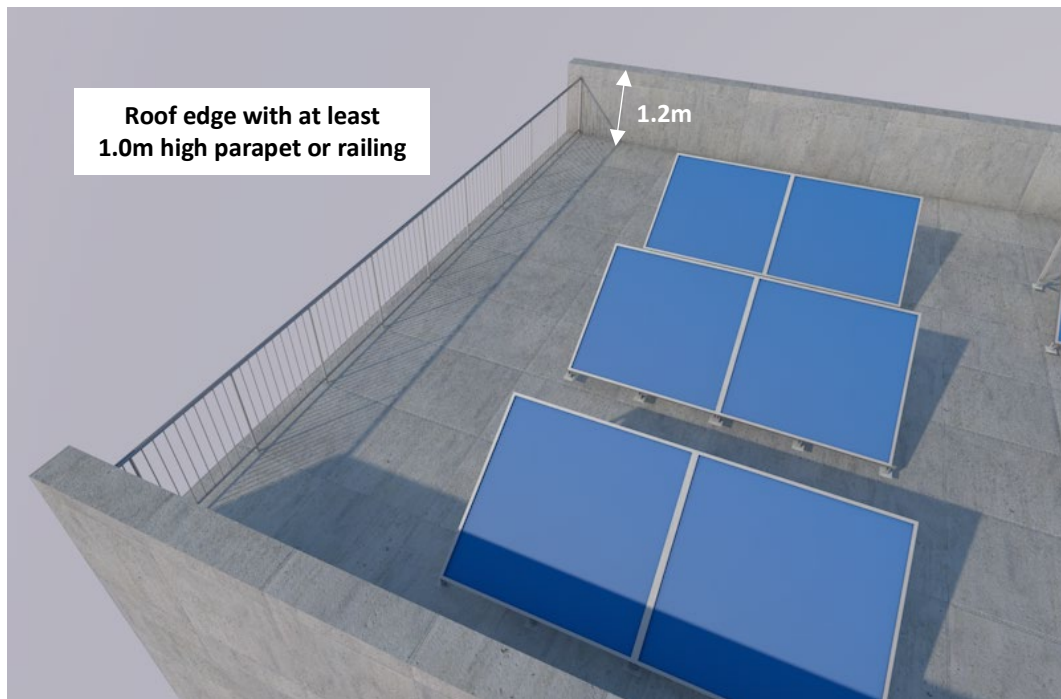


Figure 17 Design for parapet or railing

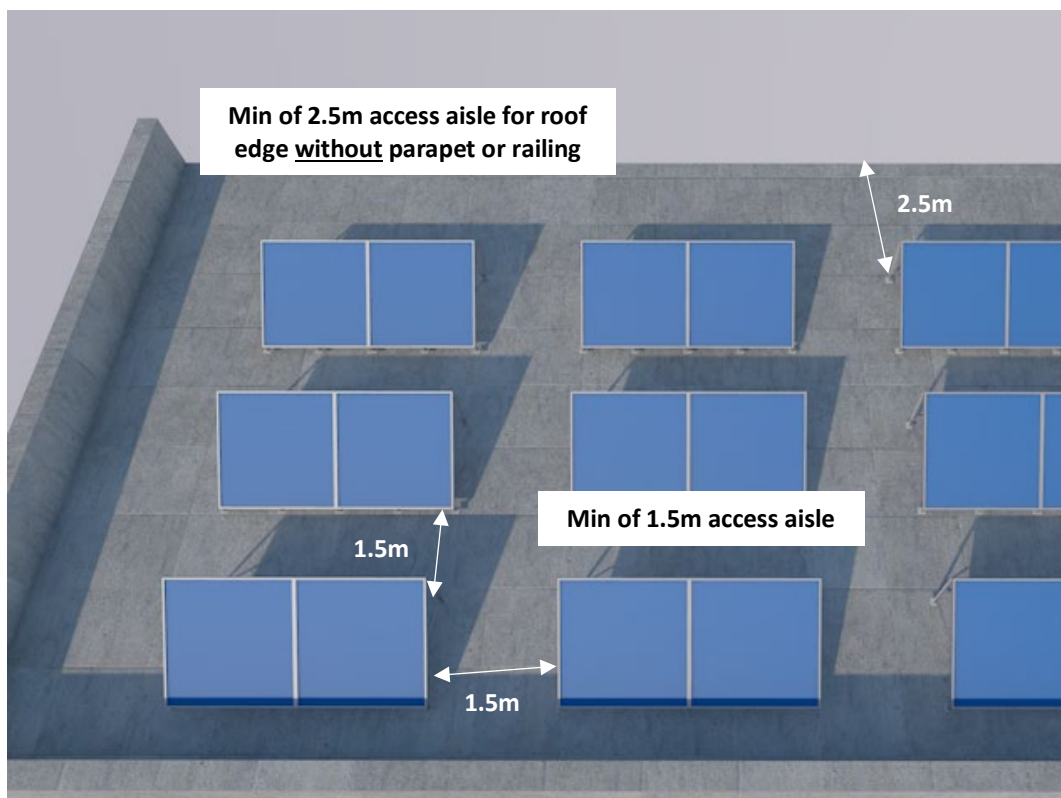


Figure 18 Design the location of the PV panels based on Fire Code

Category C: Roof and Skylight	
S/N:	C-5
Design Consideration:	M&E pipes on the rooftop of a building
Context:	The roof design of a commercial building needs to consider access for maintenance workers working on the roof.
Design Risk:	The presence of uncoordinated piping works increases the likelihood of tripping and falling of maintenance workers.
Possible Incident:	Maintenance workers may trip and fall over the uncoordinated pipes, hindering accessibility on the roof during an emergency.
Possible Design-Related Control(s) or Change(s):	<p>Substitution Group and arrange the services and locate the piping near to the wall as much as possible to facilitate maintenance and emergency access (see Figure 19).</p> <p>Engineering Control Provide crossover platforms (see Figure 19) over the pipes and include railing if the platform level difference is more than 1m.</p>
Action By:	M&E Engineer

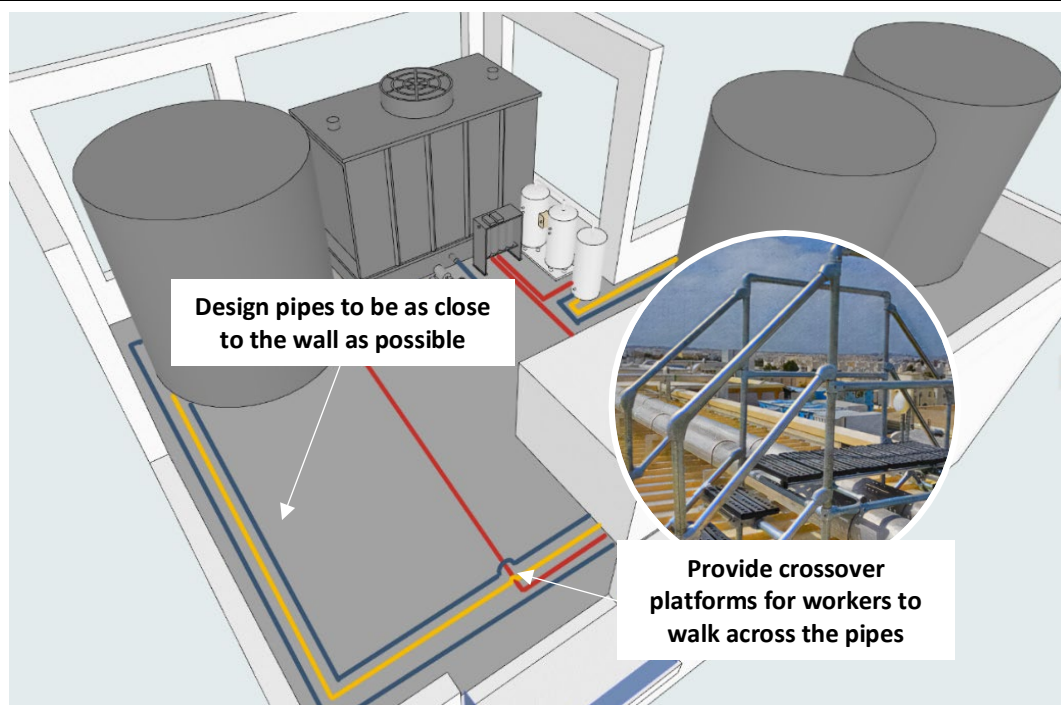


Figure 19 Recommended design-related changes for M&E pipes

Façade

Category D: Façade	
S/N:	D-1
Design Consideration:	Installation of façade with protruding aluminium vertical fin at height (>3m)
Context:	The façade of the building requires vertical aluminium fins to be manually installed on site.
Design Risk:	The presence of a façade with long protruding aluminium vertical fins that need to be installed manually by workers on the gondola increases the likelihood of workers falling from height and falling objects during construction (see Figure 20).
Possible Incident:	Fall from height when working on the gondola or struck by falling vertical fin.
Possible Design-Related Control(s) or Change(s):	<p>Elimination Remove the fin design, if possible.</p> <p>Substitution</p> <ol style="list-style-type: none"> 1. Design the fins to be part of the precast wall (see Figure 21). 2. Reduce the number and size of fins, if possible.
Action By:	Architect, C&S Engineer



Figure 20 Long protruding vertical fins that need to be installed manually by workers on a gondola

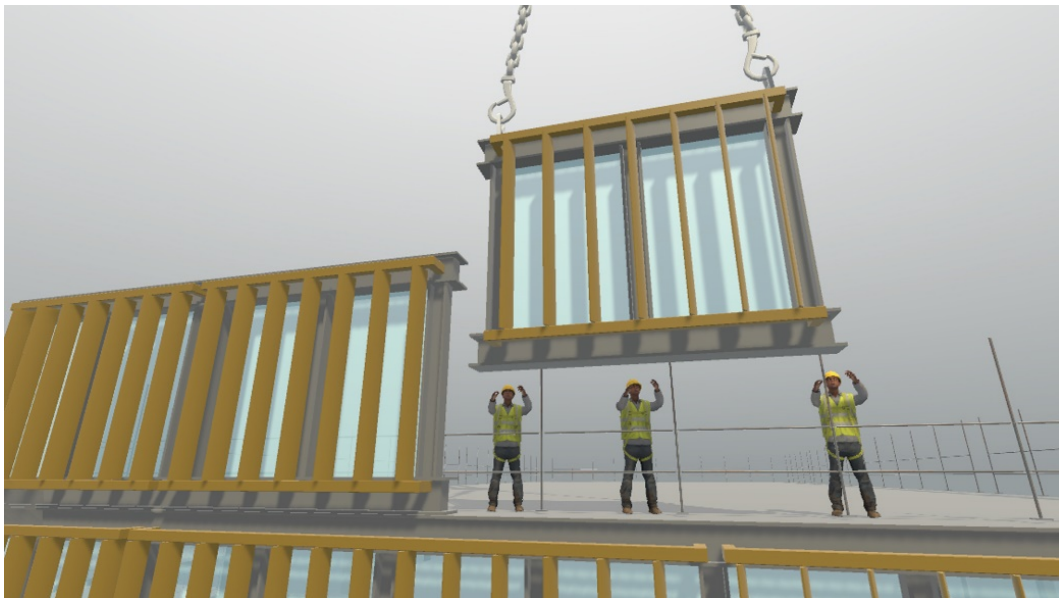


Figure 21 Vertical fins are prefabricated as part of the precast wall

Floor Openings

Category F: Floor Openings	
S/N:	F-1
Design Consideration:	Permanent floor openings for M&E services
Context:	Many floor openings (where construction workers can fall through) are protected with temporary covers such as planks and timber boards (see Figure 22) or uncovered.
Design Risk:	The presence of many floor openings increases the likelihood of workers falling from height and being struck by falling object.
Possible Incident:	The temporary cover used during construction may give way under the worker's weight or dislodge, resulting in the worker falling through. In addition, the unsafe covering can give a false sense of security to workers. If the openings are not covered, workers might fall into them accidentally.
Possible Design-Related Control(s) or Change(s):	Engineering Control <ol style="list-style-type: none"> 1. Design for load-bearing mesh or pipe sleeves (if the services are smaller) to be cast in as part of the opening to protect workers once the opening is created (see Figure 23). However, the mesh will need to be cut away as services come through. 2. An alternative is to bolt the mesh to the floor during construction. Then, remove the mesh when the services come through, but the opening is not guarded once the meshed is removed.
Action By:	C&S Engineer, Contractor



Figure 22 Floor openings with temporary covers such as planks and timber boards

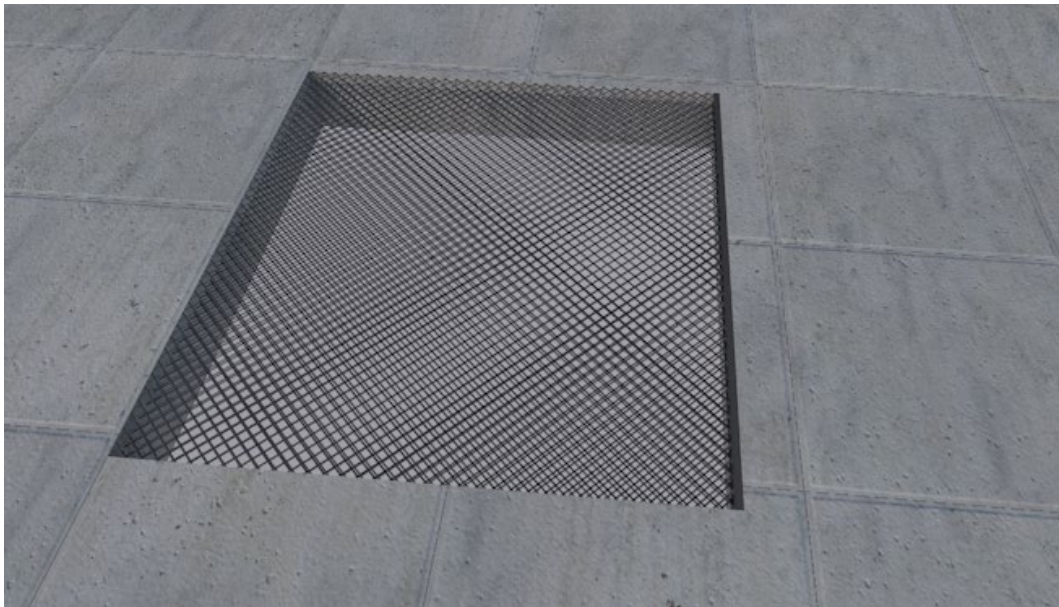


Figure 23 Cast load-bearing mesh as part of the opening

Category F: Floor Openings	
S/N:	F-2
Design Consideration:	Large temporary access floor openings in a building basement
Context:	The site is in a location where flooding risk is high—coupled with the changes in weather patterns, where heavy downpours are more common during the rainy season, the risk of flooding increases.
Design Risk:	The presence of temporary access openings increases the likelihood of flooding and accumulation of water in the basement during construction.
Possible Incident:	Flooding of the basement can lead to electrical hazards, slips, trips, falls, and drowning.
Possible Design-Related Control(s) or Change(s):	Engineering Control <ol style="list-style-type: none"> 1. To provide a low wall to prevent ingress of surface runoff into the opening (see Figure 24). 2. To account for the increased likelihood of heavy rainfall when designing site drainage systems (including pumping systems).
Action By:	C&S Engineer

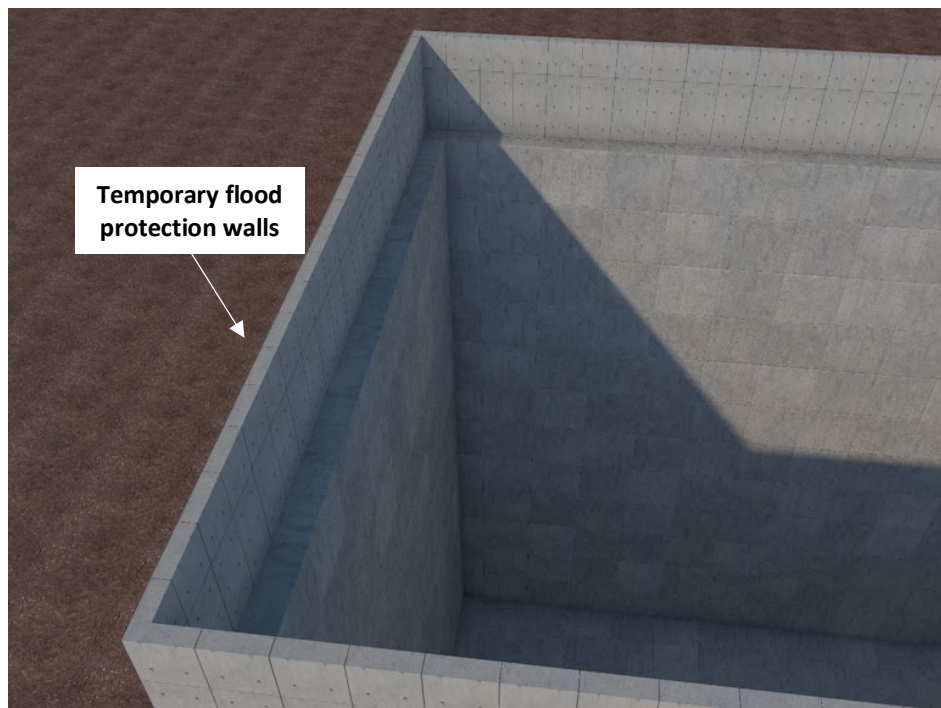


Figure 24 Temporary flood protection walls around the perimeter

Detention Tank

Category G: Detention Tank	
S/N:	G-1
Design Consideration:	Detention tank
Context:	During maintenance, workers, equipment, and material need to access and egress the 5m deep detention tank, but the access ladder is not adequately designed.
Design Risk:	The presence of an inadequately designed access ladder increases the likelihood of falling from height and being struck by a falling object.
Possible Incident:	Fall from height and struck by a falling object when accessing and egressing the detention tank.
Possible Design-Related Control(s) or Change(s):	<p>Engineering Control</p> <ol style="list-style-type: none"> 1. Design for a sufficient number of openings with cat ladders with cages and handholds at least 1m above landing (see Figure 25); retractable handholds that can extend beyond manhole opening can be incorporated. 2. Design for openings that allow easy movement of material into and out of the detention tank during maintenance. <p>Note: Designers must check against PUB's guidelines on "On-Site Stormwater Detention Tank Systems".</p>
Action By:	C&S Engineer, Architect

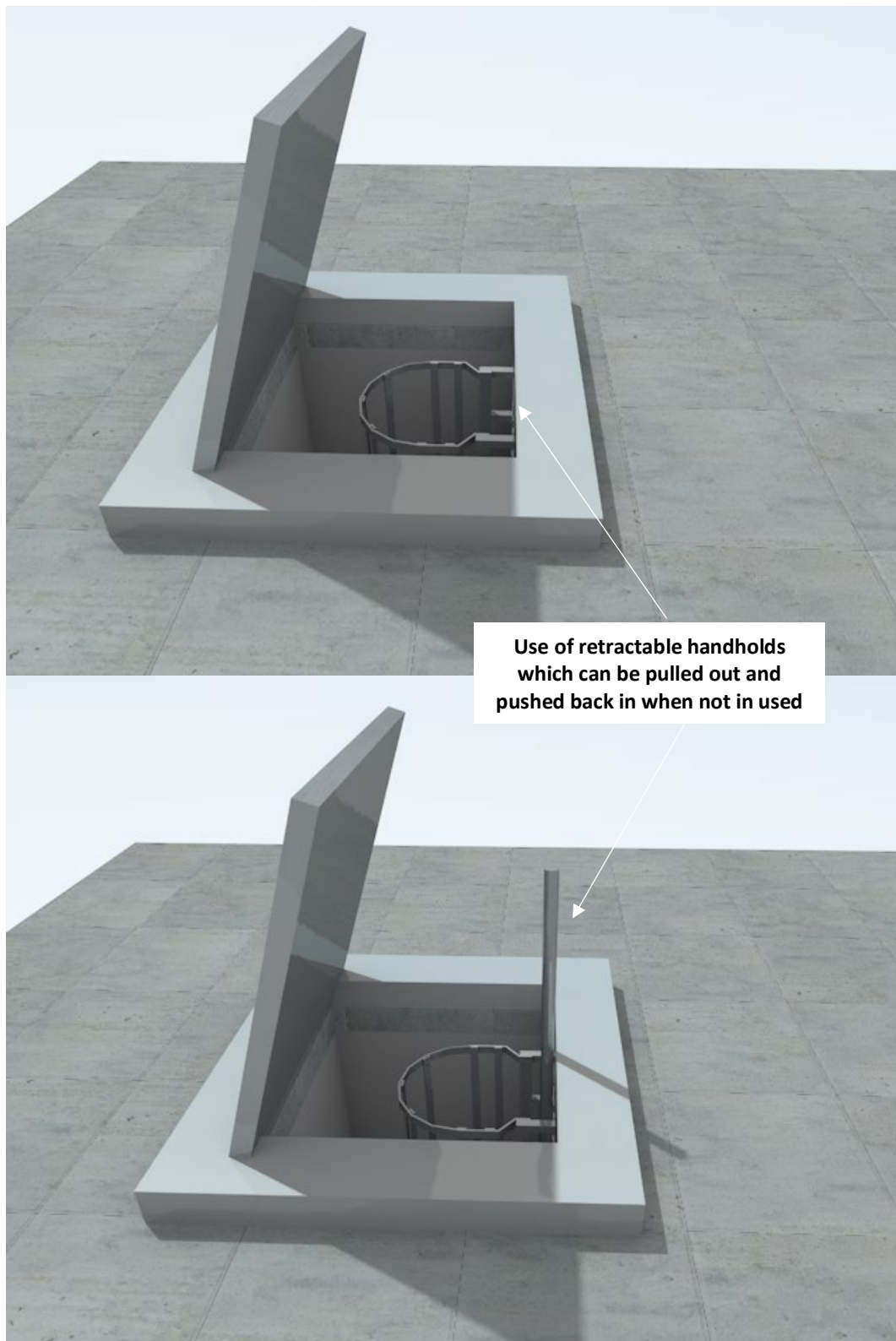
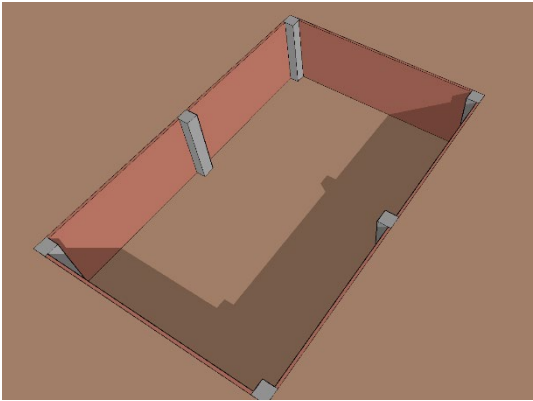
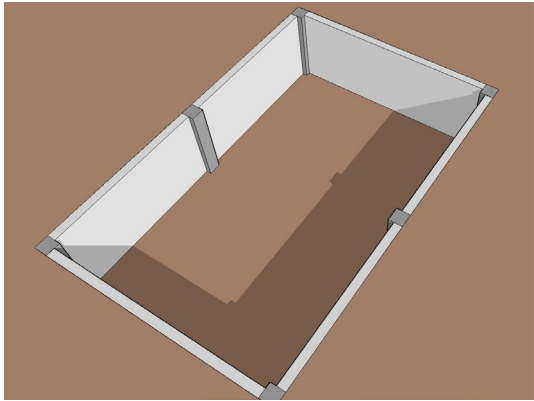
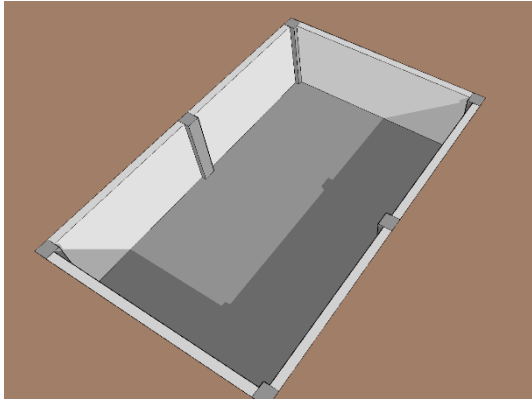
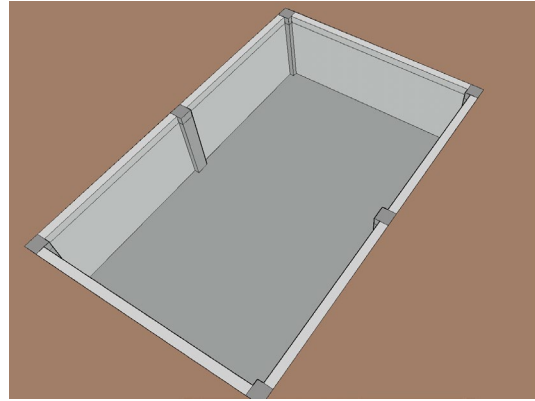


Figure 25 Access ladder with a cage with retractable handholds

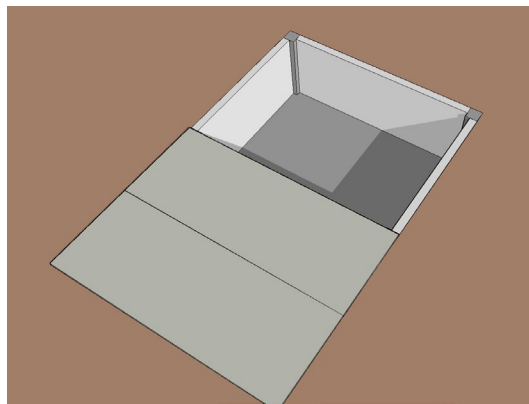
Category G: Detention Tank	
S/N:	G-2
Design Consideration:	Detention tank
Context:	Cast in-situ detention tank that requires formwork to be placed in the detention tank during casting. Formwork in the detention tank will have to be removed at the end of construction. Due to the access opening size, the formwork will have to be cut to a smaller size for removal. In addition, the detention tank has low headroom.
Design Risk:	The presence of the small openings in the detention tank makes it difficult for workers to remove the formwork, and hence workers are exposed to confined space hazards for an extended period. The low headroom also increases the likelihood of ergonomics issues.
Possible Incident:	<ol style="list-style-type: none"> 1. Asphyxiations, exposure to toxic gases, and fire and explosion in confined space 2. Ergonomic issues for workers working in low headroom conditions for an extended period
Possible Design-Related Control(s) or Change(s):	<p>Elimination Change the roof of the detention tank to be precast planks installed in segments (see Figure 26) to remove the need for formwork in the detention tank when the roof is installed.</p> <p>Substitution Provide a bigger opening to remove the formwork materials.</p>
Action By:	C&S Engineer
<div style="display: flex; justify-content: space-around; align-items: flex-end;"> <div style="text-align: center;">  <p>1. Install the structural columns.</p> </div> <div style="text-align: center;">  <p>2. Cast the walls first.</p> </div> </div>	



3. Cast the floor slab.



4. Remove the formwork materials for walls and slab.



5. Finish with precast roof for the detention tank.

Figure 26 Changing the cast-in-situ roof of the detention tank to precast planks