# Reinforcement Cage Design & Construction

## A guide to good practice

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## Foreword

Reinforcement cage fabrication and erection is one of the most important activities in construction projects. However, the assessment of their temporary stability during lifting and prior to concreting has limited guidance and is most commonly dealt with by custom and practice. There have been known collapses that have caused both death and injury.

This guidance note is written to highlight the key issues and provide recommended engineering and good practice on reinforcement cages in Hong Kong.

Contractors may consider making reference to this document for setting up their own systematic control framework to manage risks of reinforcement cage failure within construction projects. Clients may consider incorporating this document in the contract documents of their projects.

Special thanks are given to those members of the HK TWf who offered valuable comments for the updating of this document.

Practitioners are encouraged to continuously provide comments to the HK TWf at any time on the contents of this document so that improvements can be made in future editions.

Iain Mowatt
Chairman HK TWf

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### Acknowledgement

This document was prepared by the following members of the HK-TWf working group on 'Rebar Cages Stability':

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# 1. INTRODUCTION

## 1.1. Background

A large reinforcement cage can represent a considerable danger to those working on, adjacent to, or within it, should it collapse or fail during any stage of the construction work. A number of cases have been reported where a collapse has occurred. Some involved fatalities.

Collapses usually occur through lack of strength or lateral instability, or a lack of cage robustness prior to it being fully stabilised through containment within a shutter or similar. The increase in frequency of reinforcement cage collapses may also be connected to the use of Mobile Elevating Work Platforms (MEWPs) to fix reinforcement. Previously, scaffolds had been used to fix reinforcement and these probably acted as supports to the reinforcement cages where required. There also appears to be a trend towards fixing taller cages with smaller vertical bars, which also increases the chance of reinforcement cage collapse.

Examples of reinforcement cage collapses are given in **Appendix A** for reference.

## 1.2. Purpose of This Document

The lifting and temporary support of large reinforcement cages is among the most hazardous operations in construction. This is mainly due to their size, weight and inherent instability. When reinforcement cages fail, they fail catastrophically, usually with injury, loss of life and significant project disruption.

In the local industry there is generally a lack of guidance providing recommendations on good practice to ensure reinforcement cage stability throughout the construction process.

The purpose of this document is to provide a reference document that summarizes key issues and recommends good practices and engineering guidance for the handling of reinforcement cages.

The following are discussed in this document:

a) Chapter 2 discusses key issues related to reinforcement cage stability;
b) Chapter 3 outlines the recommended reinforcement cage design and construction process;
c) Chapter 4 summarizes the roles of key personnel and their responsibility associated with the design, execution and supervision of reinforcement cages;
d) Chapter 5 provides recommendation on construction engineering of reinforcement cages;
e) Chapter 6 includes a series of checklists that can be used to ensure proper procedures are undertaken at each stage of works involving reinforcement cages;
f) Chapter 7 provides a list of references.

## 1.3. Target Audience

**Who should use this document?**

The primary audience for the document includes construction engineers working in one of the following two roles:

1) Supervisory construction personnel responsible for construction operations for the contractor either directly or in a consulting engineering capacity, or;
2) Resident Engineers or Engineers representing the employer in a construction administration and/or inspection capacity.

For (1), the engineer is assumed to have the responsibility and authority for the engineering design of the temporary support system and may also have oversight of the lifting/trip operation. For (2), the engineer is assumed to have overall review and inspection authority in the context of life-safety and employer's interests.

The secondary audience for this document is all of the stakeholder roles in the design and construction of reinforcement cages. This includes permanent works designers, fabricators, rebar subcontractors, rigging and lifting personnel, as well as employers. Some engineering knowledge is assumed (e.g. statics, forces, understanding of structure loadings), but all of these constituents should benefit to some degree from reading this document.

***If you are a construction engineer representing the contractor or the employer...***

This document is essential because it bridges the gap between the requirements of the design and specifications and any applicable health and safety procedures.

a) Chapter 3 describes recommended process for cage design and construction;
b) Chapter 4 describes guidance for distributing responsibility in the cage construction process;
c) Chapter 5 outlines the recommended construction engineering guidance for supporting cages;
d) Chapter 6 provides good practices for field operations.

***If you are a fabricator...***

This document will present a recommended design and construction process to help envision the downstream operations involved with the lifting and placement of reinforcement cages.

a) Chapter 3 describes recommended process for cage design and construction;
b) Chapter 5 describes the requirements for temporary support system selection, design, and installation;
c) Chapter 6 provides good practices for field operations.

***If you are a permanent works designer...***

This document will provide some insight into the hazards associated with lifting and placement of reinforcement cages, particularly large ones, and provide suggestions for improving constructability and stability during the temporary condition.

***If you are a rigging engineer, crane operator or lifting crew...***

This document will be important for identifying the distribution of responsibility and authority throughout the design and construction process.

a) Chapter 3 describes recommended process for cage design and construction;
b) Chapter 4 describes guidance for distributing responsibility in the cage construction process;
c) Chapter 6 provides good practices for field operations.

***If you are an employer...***

This document is useful in understanding the unique issues involved with reinforcement cages including their size, weight and inherent instability.

a) Chapter 1 introduces the problem, the document structure, and approach;
b) Chapter 2 discusses various key issues associated with reinforcement cage stability;
c) Chapter 3 describes recommended process for cage design and construction;

For all users, this document will provide guidance for the handling of reinforcement cages when neither specifications nor engineering (designer) requirements nor safety regulations do so.

## 1.4. Scope of This Document

Reinforcement cages for walls, columns, beams and slab elements, either fixed in-situ or prefabricated, are considered within this document both for lifting and stability in place prior to concreting.

**What This Document Does Not Provide**

While it would be desirable to address all aspects of the engineering and construction of cages, certain aspects are not covered in this document so as to keep the scope focused:

a) Reinforcement cages placed in piles / diaphragm walls are beyond the scope of this document. Guidelines on fabrication of bored pile reinforcement cages is provided in the "Guidelines on Fabrication of Reinforcement Cages of Bored Piles" published by the Hong Kong Construction Industry Council.
b) This document does not give detailed guidance on how to perform structural analysis of reinforcement cages supported by internal or external support systems. There is wide variation in the preferred methods used. These range from indeterminate structural analysis, to moment frame analysis, to full finite element modelling using commercial software. The construction engineering good practices provided in this document are intended to define the parameters and requirements for the structural analysis, but the analysis techniques to be used are at the discretion of the engineer.
c) Construction lifting operations are not covered in detail in this document nor are rigging requirements for reinforcement cages. It is assumed there is considerable expertise in this area that is already widely deployed in practice.

# 2. KEY ISSUES

Key issues associated with reinforcement cage stability that warrant particular discussion can be attributed to lifting and stability prior to concreting.

## 2.1. Lifting of Reinforcement Cage

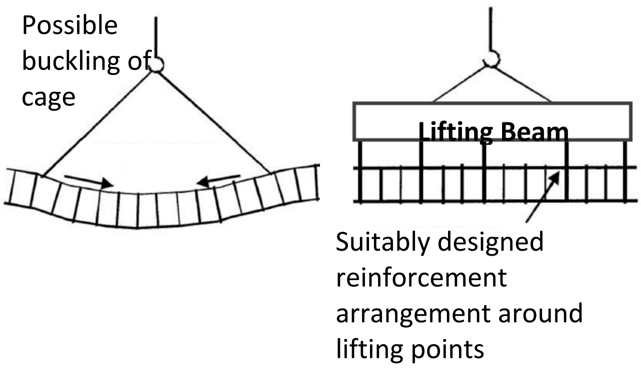



***Figure 2.1 – Buckling of cage due to axial forces and designed lifting points***

### 2.1.1. Regulations and Standards

The Factories & Industrial Undertakings (Lifting Appliances and Lifting Gear) Regulations and relevant practice notes regulates the safe use of lifting equipment. However, there is no specific guidelines on the lifting of reinforcement cages. The British Constructional Steelwork Association (BCSA) 'Guide to the Management of Site Lifting Operations' contains additional guidance, although not specific to lifting of reinforcement.

### 2.1.2. Modes of Failure During Lifting

Potential modes of failure to be considered when planning lifts include:

a) Instability of the crane (or lifting plant).
b) Failure of lifting equipment (strops, chains, bars, shackles, lifting eyes etc).
c) Lifting points ripping off the cage.
d) Inadequate load path from the lifting points.
e) Axial buckling due to compression caused by inclined chains/strops.
f) Bending failure with scissor action at laps or excessive deflection of cages (requiring stiffening by inclined bars, links or U-bars).
g) Laps and splices give way (tied laps frequently experience relative movement of around 25mm before failure).

## 2.2. Reinforcement Cage Stability

### 2.2.1. Typical Modes of Failure

Elements can fail in a variety of ways depending on the size and shape of the element and how it is moved or placed. Typical examples are illustrated in **Figure 2.2** below.

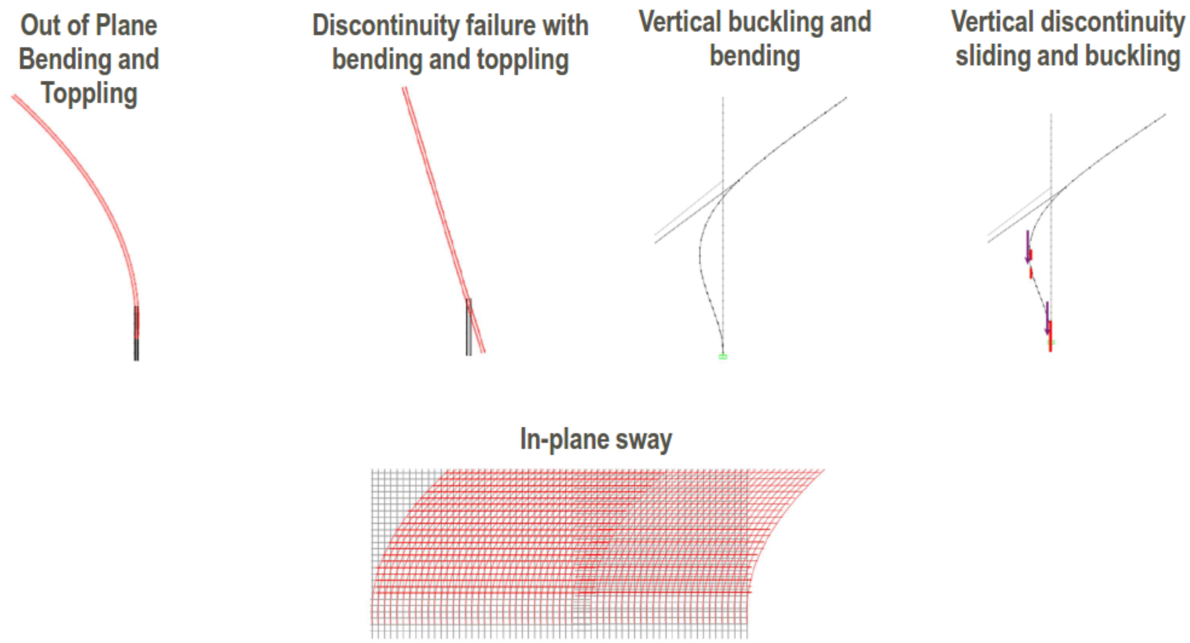



***Figure 2.2 – Typical failure modes of reinforcement cage***

#### 2.2.2.2 Foundation Elements

Larger foundation elements, built in-situ, generally fail due to the insufficient support of the top mat on chairs or similar.

#### 2.2.2.3 Column and Wall Elements

Column and wall elements can fail by the shape not being maintained, and also by overturning if the connection to the starter bars is insufficiently robust.

The failure mechanism for vertical members tends to be by the failure of the spacers between the mats leading to the mats separating and acting individually, causing a reduction in the section resisting overturning. Another mechanism is for the ties between the starters and the cage to fail.

The presence of L-bars as starters to the top of the column or wall, for slabs can introduce an eccentric load at the top of the member, decreasing the stability of the element.

### 2.2.2.4 Slab Elements

Slab elements can fail due to the insufficient support of the top mat on chairs or similar.

### 2.2.2.5 Beam Elements

Beam elements can fail by racking of links or buckling of upper bars. Deep beam elements can be laterally unstable.

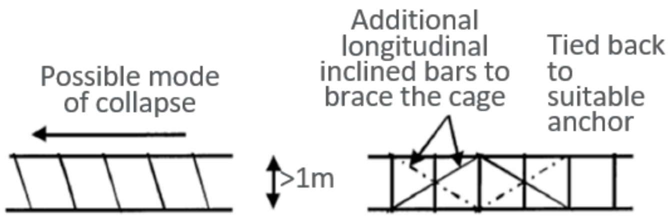



***Figure 2.3 – Elevation on beam or deep base showing racking of cage and additional inclined bracing bars to provide stability***

## 3. REINFORCEMENT CAGE DESIGN AND CONSTRUCTION PROCESS

Like many construction operations, the design and construction of a concrete cast-in-place structure, including its reinforcement cage, is a distributed process. Different entities perform different roles; have different responsibilities, yet they must all function collaboratively, safely and efficiently. The purpose of this Chapter is to highlight the “soft side" of the reinforcement cage design and construction process, particularly an explanation of the lifecycle that follows cages from design all the way through construction. The distribution of responsibility and authority is discussed, as is a general framework for handling risks associated with reinforcement cages.

There is a wide variation in the construction engineering and construction practice for reinforcement cages. Some contractors may use a turnkey approach and are responsible for fabrication, erection and placement of concrete formwork. Some contractors may appoint a fabricator to deliver a pre-assembled cage to a job site, which is in turn rigged/lifted by a subcontractor and turned over to another for formwork. A few contractors may have corporate policies and procedure manuals for handling temporary works, including reinforcement cages. Smaller contractors, by contrast, work based on the experience of their superintendents and foremen and have no such materials.

This Chapter provides recommended process as depicted in **Figure 3.1**, which is generally applicable and designed to map to defined lines of responsibility mentioned later in Chapter 4.

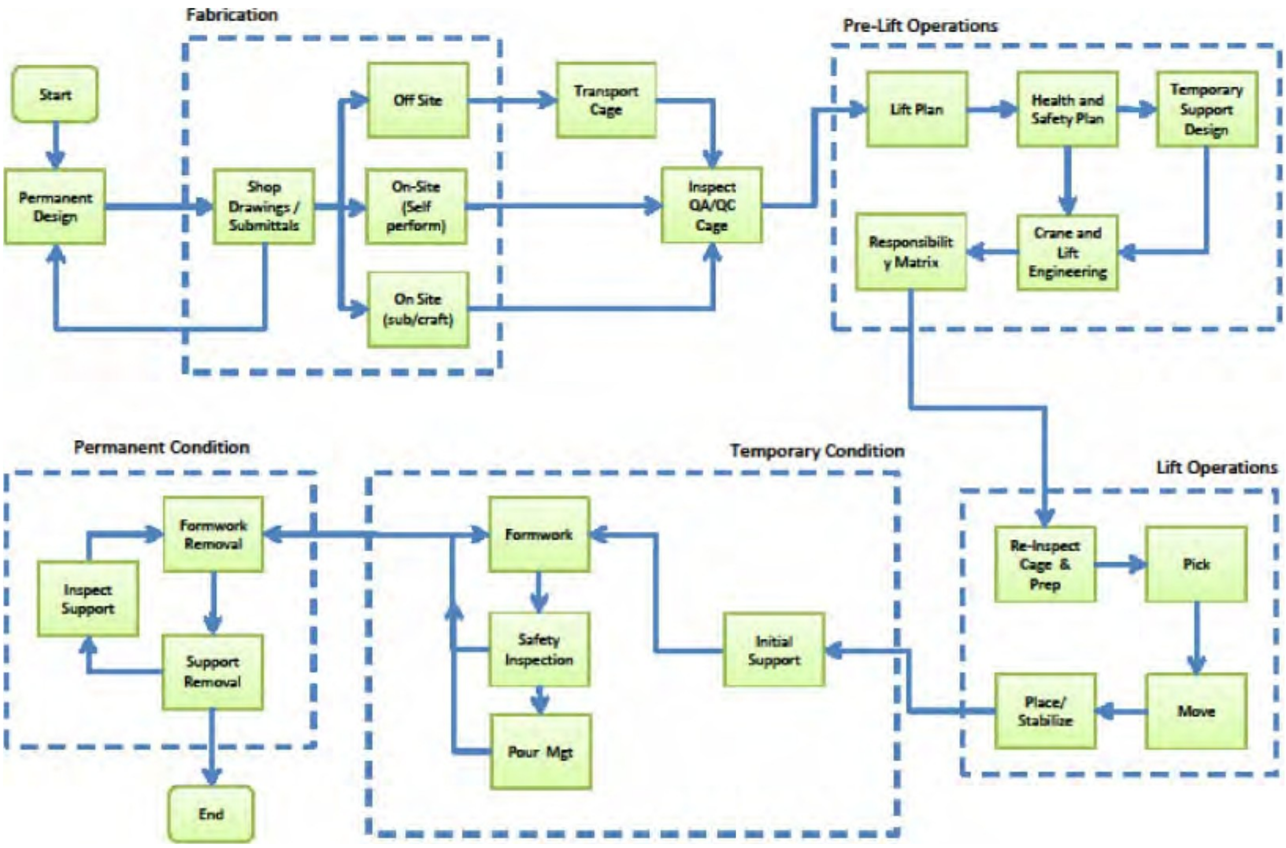



***Figure 3.1 – Flowchart for reinforcement cage design and construction process***

The flow chart is divided into five process areas each of which is described in the following sections.

## 3.1. Permanent Works Design

The start of the process is for the cage geometry and reinforcing steel to be designed by a permanent works designer. It is uncommon for permanent works designers to design bracing, reinforcement for lifting, or reinforcement for improved lateral stiffness in the temporary condition. This will instead be done by a fabrication shop or rebar subcontractor with details of bracing, tying details, additional pick-up reinforcement, etc. shown in shop drawings.

Notwithstanding this, the permanent works designer should, however, be involved in a construability and coordination review to ensure the cage design is reasonable considering the constraints of the site and that no unnecessary safety hazards are imparted on construction personnel due to the required lifting or placement of the cage. It is recommended the permanent works designer should also consider to:

1) Allow for some minimum internal bracing in the permanent works drawings;
2) Make clear the desired base condition for the cage in the drawings and specs so that all "downstream" parties (fabricator contractor, construction engineer) can plan accordingly.

## 3.2. Fabrication

Fabrication occurs next where the reinforcement cage is assembled either off-site at a fabrication shop or on-site by steel fixer. Smaller cages assembled in fabrication shops are easily transported to the site and have the advantages of factory quality control and just-in-time delivery for placement (i.e. no site staging required). A possible disadvantage is that if these off-site suppliers of pre-assembled cages play no role in lift (trip) operations, they may not detail cages for this purpose. Turnkey rebar subcontractors that provide both fabrication and lift services are more likely to engineer cage details and lift requirements concurrently.

For larger or more complicated cages, on-site fabrication may be necessary. Assembly and lifting may be done by a single entity or by two entities coordinated by the general contractor. Stability of the cages shall always be considered throughout the assembling process.

No matter the fabrication method, safety hazards from workers placing bars for the cage assembly exist. Cage accidents have occurred during the fabrication process while still horizontal and even in fabrication shops with experienced personnel.

Upon completion of the fabrication process, inspection for verification of the reinforcing design is crucial. This may include:

a) Verification of all number, location and size of bars as designed by the permanent works designer and approved through applicable submittals by the fabricator.
b) Verification of type and location of wire ties, e.g. are ties of acceptable quality as per the permanent design/submittals?
c) Quality assurance for the pre-lift cage condition. Was it assembled on level ground? Is it racked, twisted, or out of alignment?
d) Have lift points been specified or clips installed and inspected for the lift?

The completion of the inspection process shall constitute acceptance of the fabricated cage.

## 3.3. Pre-Lift Operations

Planning for lift operations for reinforcement cages can be done concurrently with the fabrication process.

An appropriate lift plan prepared by qualified rigging and crane operating personnel is required. Lifts for reinforcement cages must first and foremost account for the loads and geometry of the cage to be lifted, but also for anticipated deflections and site interferences. In general, the ideal method for upending (tripping) any large cage is to use two cranes, one attached to the head end and the other attached to the tail end. In situations where only one crane is available or when site conditions limit access for two cranes, crane model-specific guidance has been developed (Billodeau, 2010). In general cages being lifted by one crane shall use two lines, whereby the total weight being lifted by the two lines must be less than the lesser capacity of either of the two lines. A single cage being lifted by two hooks is considered one load.

In addition to a detailed and appropriate lift plan, pre-lift operations require review of contractor or other health and safety plan information. Ideally, these plans describe how personnel are allowed to work on or around a cage during the lifting and erection process. The temporary support system design, to be discussed in detail in Chapter 5, must be complete. It will include engineering calculations and checks based on the cage to be placed, the support system required (e.g. symmetrical guy wires), and the constraints of the site. Coordination between the lift plan, health and safety plan, and temporary support system shall be done iteratively. This expands upon the normal levels of approval that are part of a standard lift plan to include roles and responsibilities throughout the entire rebar design and construction process.

## 3.4. Lift-Operations

Detailed guidance on crane operations is beyond the scope of this document. The reader shall refer to other relevant local guidelines and regulations.

## 3.5. Temporary Condition

The temporary condition is arguably the most important part of the overall reinforcement cage process. This is because even highly engineered cages, lifts, and support systems can still result in collapse, injury, or death if the temporary supports are changed, prematurely removed or damaged.

The contractor is almost always responsible for the project under construction. He or she has ultimate supervisory control.

## 3.6. Permanent Construction

The culmination of the rebar design and construction process is a permanent structure capable of supporting its own weight service loads, as well as lateral loads as per its design. For tall cages, the casting process for concrete is segmental. It is possible for the lower portions of a structure to be considered permanent while any exposed length not cast in concrete is considered temporary. Numerous accidents have occurred for partially complete structures where the base of the structure was cast. Vigilance and care is needed until the entire structure is cast, formwork removed, and the temporary support system removed.

# 4. ROLES AND RESPONSIBILITY MATRIX

A responsibility matrix is a common tool used to map the required activities for a work operation to specific roles or individuals. Our recommended responsibility matrix is given in **Table 4.1** and may be used for each cage or cage group for the overall design and construction process. The five processes defined for the standard flowchart comprise the activities illustrated in **Figure 3.1**.

Three levels of responsibility are assigned in the matrix: no responsibility (blank), direct responsibility (R) or consulting responsibility (C). The concept here is for a single individual to "own" responsibility for an activity in the process, regardless of how it is distributed amongst fabricators, sub-contractors, or construction engineers.

The matrix provided is meant only as a guide. Individual teams should tailor their own matrix to capture the unique requirements of their project.

It is recommended that the contractor's site organization shall include names and CVs of all those key personnel shown in **Table 4.1**.

**Table 4.1 – Roles and Responsibility Matrix**

| Process | Permanent Works Designer (PWD) / Employer Representative | Temporary Works Designer (TWD) | Temporary Works Coordinator (TWC) | Construction Manager or representative | Project Manager or representative | Fabricator | Foreman | Responsible Individual Name |
|---|---|---|---|---|---|---|---|---|
| **Fabrication** | | | | | | | | |
| Permanent works design and constructability | R | C | | C | | | | |
| Design of longitudinal pick-up bars | | C | | C | | R | | |
| Design of internal bracing | C | C | | | | R | | |
| Tying requirements | | | | C | | R | | |
| Quality Control, Inspection, Verification | | | | R | | | | |
| Design/Spec of lift points | | R | | C | | | | |
| Ensure temporary works design is in place | | | R | | | | | |
| | | | | | | | | |
| **Pre-Lift Operations** | | | | | | | | |
| Site management | | | | R | | | | |
| Health and safety plan | | | | | R | | C | |
| Crane access/staging | | | | R | C | | | |
| Lift plan | | C | | R | C | | | |
| Design of temporary support | | R | | C | C | | | |

| Process | Permanent Works Designer (PWD) / Employer Representative | Temporary Works Designer (TWD) | Temporary Works Coordinator (TWC) | Construction Manager or representative | Project Manager or representative | Fabricator | Foreman | Responsible Individual Name |
|---|---|---|---|---|---|---|---|---|
| Ensure lifting plan is in place | | | R | | | | | |
| | | | | | | | | |
| **Lift Operations** | | | | | | | | |
| Preparation/equipment verification | | | | R | C | | C | |
| Issue permit to lift | | | R | | | | | |
| Pick/lift | | | | C | | | R | |
| Move | | | | C | | | R | |
| Stabilize/place | | C | | C | | | R | |
| Reinspect the integrity of cage and carry out remedial works | | C | | C | | C | R | |
| | | C | | C | | | R | |
| **Temporary Condition** | | | | | | | | |
| Initial support | | C | | C | | | R | |
| Formation installation | | | | | | | R | |
| Safety engineering | | | | R | | | | |
| Pour management | | | | | | | R | |
| Issue permit to pour concrete | | | R | | | | | |
| Formwork removal | | | | | | | R | |
| Support removal | | C | | C | | | R | |
| | | | | | | | | |
| **Permanent Condition** | | | | | | | | |
| Inspection | R | | | C | | | | |
| Acceptance | R | | | C | | | | |

Expected roles of the key personnel are discussed below.

## 4.1. Permanent Works Designers (PWD)

Despite details such as fabrication and lifting of the rebar cages are normally proposed by the contractor, PWD shall give consideration to the buildability of the rebar cages at the permanent works design stage as far as practical. This should have included consideration of the detailing of, for example, any identified splices and construction joints to ensure so far as is reasonably practicable that the specified reinforcement cages are not inherently unstable.

PWD must give consideration to situations where significant risks might arise from their design, e.g. the configuration, weight, stability, size etc. of reinforcement cages, and where the significant risk could be reduced by reasonable actions by the PWD. Where significant risk remains, this must be brought to the attention of the contractor. “Significant risk” is where it is not likely to be obvious to a competent contractor; unusual; or likely to be difficult to manage effectively.

## 4.2. Temporary Works Designers (TWD)

TWD must give specific consideration to reinforcement cages and ensure the design is such that lifting and stability in place is achieved safely. Information on significant residual risks should be passed onto the contractor.

## 4.3. Temporary Works Coordinator (TWC)

TWC has the responsibility of ensuring that all parties are working together, coordinating their works and ensuring the temporary works procedures are followed and issuing necessary “permit to work”.

TWC is expected to be responsible for the coordination of the following aspects:

a) Identification of significant risk items such as large and potentially unstable cages, items to be lifted, etc.
b) Identification of potential solutions such as review the proposed construction method, introduce stability elements (additional reinforcement or bracing), etc.
c) Communication co-ordination and consultation meetings/tool box talks, temporary works design, drawings, method statement (safe system of work)
d) Control procedures supervision
e) Formal inspection/permission procedure (permit to load / lift) monitoring and feedback

Typical roles and requirements of TWC is described in the document “Control and Management of Temporary Works” published by the Hong Kong Temporary Works Forum.

## 4.4. Fabricator

The fabricator has the biggest role to play in increasing the lateral stiffness of the cage. The goal is to prevent catastrophic bucking of the cage, and with sufficient internal bracing, proper ties, and sufficient pick-up and longitudinal bars, if a collapse occurs it will be gradual and will minimize risk to workers.

## 4.5. Bar Fixing Foreman

Bar Fixing Foremen should be appointed to supervise all working procedures in order to ensure compliance with the method statement. It is recommended that the Bar Fixing Foremen shall possess at least 10-years’ experience in bar fixing. Fabrication drawings should be disseminated to Bar Fixing Foremen in order to ensure fabrication procedures are followed properly and safely. Prior to the fabrication, Bar Fixing Foremen should give briefings about the method statement and work procedures to all bar fixing workers involved. If safety measures are found to be insufficient, the foreman has the authority to stop the fabrication work. Upon completion of the fabrication, Bar Fixing Foremen should check whether the reinforcement cages comply with the fabrication drawings before any subsequent lifting operation and installation.

The typical relationship between the TWD, TWC and Bar Fixing Foreman is illustrated in **Figure 4.1** below.

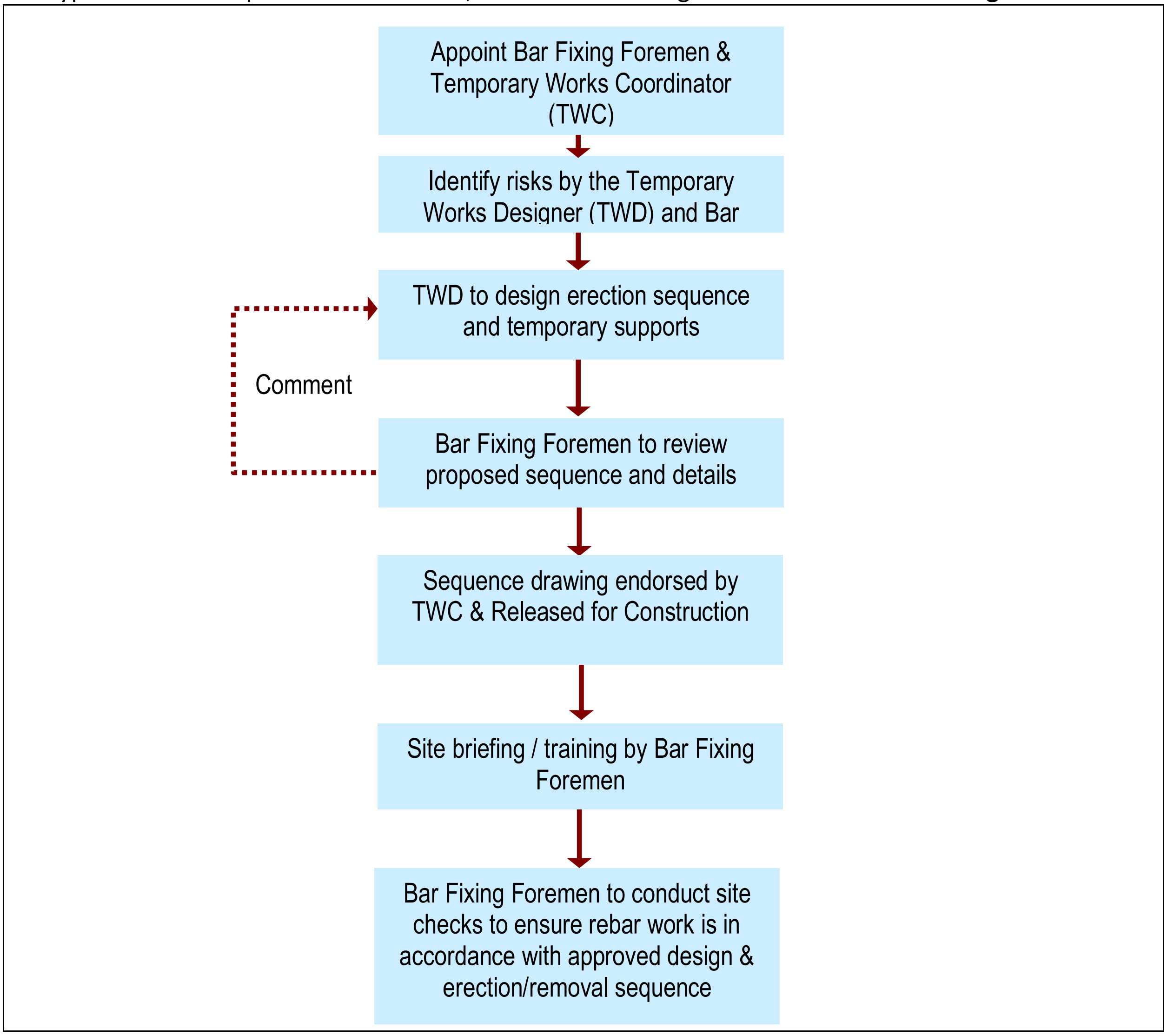



***Figure 4.1 – Typical relationship between TWD, TWC and Bar Fixing Foremen***

# 5. RECOMMENDED CONSTRUCTION ENGINEERING OF REINFORCEMENT CAGE

Chapters 3 and 4 have discussed the overall process, roles, and responsibilities involved in the design and construction of reinforcement cages. This chapter focuses on the construction engineering aspects and good practices for temporary support system selection, design, and installation, and the engineered installation, modification, and removal of the support system. Some examples of good practice are illustrated in **Appendix B**.

## 5.1. Temporary Support Systems

The engineering of a temporary support system for above-grade reinforcement cages is difficult due to the structural analysis of the semi-rigid cage. Lateral loading conditions and site-constrained placement of bracing or guying are also challenging. The process begins with load determination, followed by selection of supporting system, structural analysis, design, installation and modification plans if required.

### 5.1.1. Determination of Loads

Service loads for the permanent conditions are determined as part of the permanent design and are separate from the loads that impact a reinforcement cage during construction. The load considerations for the design of a reinforcement cage support system should include the following wherever applicable:

a) Dead loads – this includes the self-weight of the reinforcement cage, laps, additional bracing, en-cast items and couplers, etc. This can be determined from the fabricator's bill of lading for the cage, shop drawings, or field estimates. If at any time the support system will be attached to forms, the weight of those forms should be added to the self-weight of the cage.
b) Construction (live) loads – this includes loads imposed during the construction processes such as personnel, material and equipment loads.
c) Erection and fitting loads – this includes forces caused during the erection process such as during aligning, fitting, bolting or guying.
d) Wind load – reinforcement cages should be designed and stabilized to resist wind loads during construction. The wind load to be applied should be determined based on local requirements and guidelines.
e) Impact loading (value to be determined by the designer depending on the level of risk and the consequences of failure) typically varies from 0 – 10kN.
f) Dynamic loading when being lifted (typically 10% to 25% of dead load depending on the type of crane being used).
g) Nominal loading to take account of distortions (typically 2.5% of dead load but should be determined by the designer).

Not all these loads occur at the same time, so the designer should make appropriate judgements to determine the most onerous combination that is likely to exist.

### 5.1.2. Selection of Supporting System

The temporary support system chosen should depend on the constraints of the site, cage size and configuration, and expertise of the installing contractor. Many use standard specifications that require that temporary guying or bracing be provided, as necessary, to withstand all imposed loads during erection, construction and removal of any falsework. It is recommended that all reinforcement cages with a height/breadth ratio greater than or equal to 8 must be supported. All engineered support systems, regardless of the type used should be sealed and stamped by a TWC. Support systems may be external, internal, or if the cage is sufficiently rigid, they may be omitted.

Particular attention is drawn to the rebar cage erection for top-down construction. Unlike conventional bottom-up construction method where stable structure (e.g. previously cast reinforced concrete slab, etc.) is normally available at the base for the sitting of the rebar cage, stable base may not be available for top-down construction. Appropriate supporting system for the rebar cages shall be developed taking into account the specific site condition adjacent to the rebar cages.

External supports include struts in the form of pipes or timber (recommended only for very short cages) or telescoping poles such the pole braces shown in **Figure 5.1** (left). Struts in this case should resist both tension and compression and are a good choice for reinforcement cages less than 6m tall. A minimum of two strut braces should be used, placed at 90-degree angles to one another. They should be rigidly attached (i.e. lagged or bolted) to the cage and to anchor blocks on the ground to resist lateral movement as shown in **Figure 5.1** (right).

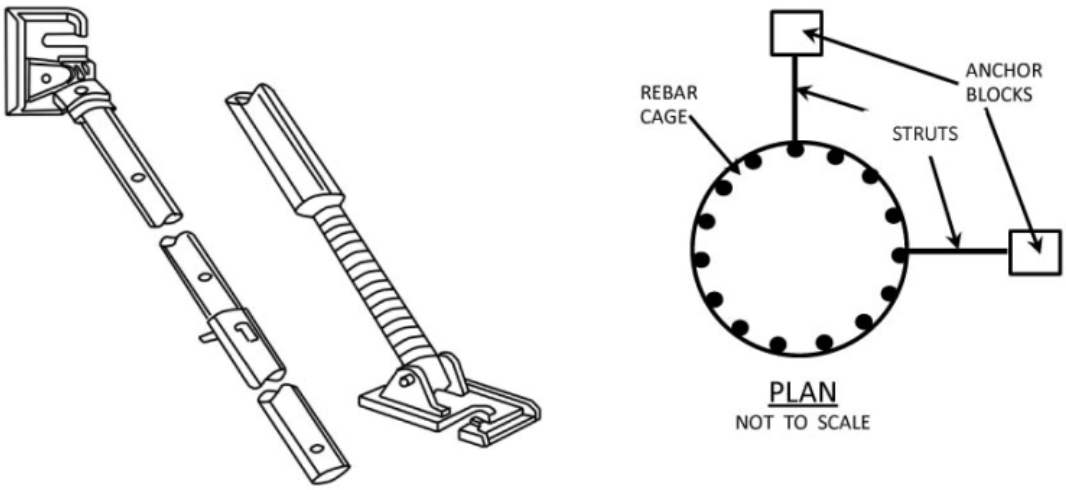



***Figure 5.1 – (Left) Adjustable pole brace. (Right)Typical external bracing of rebar column cage using struts and anchor blocks***

Guy wires are another external support system. Inclined wires act in tension between the reinforcement cage and anchor blocks on the ground to resist opposing lateral loads. Guys are placed symmetrically around the cage to resist lateral forces and are the recommended option for cages taller than 6m. The use of four guy wires placed 90 degrees apart is common. Before selecting a guy wire system, verify that site conditions are compatible (wire angles will not be too steep, anchor blocks, anchor points are accessible and adequate, etc.). Guy wire inclination to the horizontal is ideally 45 degrees but should be no more than 60 degrees. Guy wire angles in excess of 60 degrees create excess downward force for which the longitudinal bars in the cage may not be designed to resist in the temporary condition. Multiple-level guy systems should be used for cages taller than 12m or when guy wire angles are too steep.

Horizontal supports (either cables or solid members) that hold the cage by “clotheslining" is another external system. This technique allows the cage to hang from the horizontal supports as if being attached to a clothesline. This is applicable only for relatively light cages and should not be the sole bracing used.

Internal support systems that are capable of supporting the reinforcement cage entirely from within exist as well. These systems may be the only option for marine construction or where no external system can be anchored to the ground. An internal guying system consists of a rigid pipe or structural frame that supports the self-weight of the cage and resists lateral loads.

Finally, the engineer may select no support system if the cage based on its reinforcement design is sufficiently rigid and if the H/D ratio is low (e.g. less than 2). Rigidity can be enhanced in the cage through the inclusion of internal bracing or field techniques that add strapping or spot welds. Such measures are subject to review and approval by the permanent works designer as they may affect the engineering performance of the permanent works.

It is common for multiple support system configurations to be selected/designed and only the best alternative be implemented. It is also common for hybrid systems that use a combination of external and internal systems. Finally, the type and configuration of the support system may change during construction as concrete is cast and form work erected along the length of the cage.

### 5.1.3. Structural Analysis

Temporarily supported reinforcement cages subject to lateral loads are statically indeterminate structures. Determination of the resistance forces to lateral loads can be achieved for braced or guy systems using established structural analysis procedures. The standing reinforcement cage can be idealized as a beam-column system, but the lack or rigidity in the cage complicates the analysis.

It may not be practical to impose the requirement for structural analysis for all rebar cages. Sometimes simple assessment or typical details may be appropriate for small rebar cages. There is currently no established guidelines as to when and where structural analysis should be performed. It is recommended that the site foremen be responsible to assess such requirement based on the rebar cage geometry and risks, and consult the construction manager and temporary works designer as necessary.

For complicated or high-risk rebar cages where structural analysis is necessary, analysis using a finite element method software package is recommended. A 2D (assuming symmetrically placed braces/guys) or 3D analysis can be used to solve for the needed resistance forces in the selected internal or external support system. If the cage is assumed to be rigid, frame analysis may also be used.

The goal of the structural analysis is to determine the reaction forces at the temporary supports and at the connections. Understanding of the base condition of the structure is important in selection and design of the support system. Lap-spliced base connections (footing dowels tied to longitudinal bars) are idealized as pinned connections. Mechanically spliced base connections (with an approved mechanical rebar coupler) may be idealized as fixed. Pinned connections should be assumed if unspecified or unknown.

It is common practice to perform the structural analysis based only on the gross geometry of the cage and constituent number and size of bars. Internal bracing added by a fabricator or rebar subcontractor is usually not accounted for and may improve the rigidity of the cage. Consequently, a conservative estimate of resistance forces needed in the support system may result.

### 5.1.4. Design

The design of the temporary support system involves sizing of the bracing/guying components and determining the configuration of anchor blocks. Only design considerations for bracing/guying systems are presented here. Internal guying using pipes or internal frames is relatively rare and uses more specific structural design steps.

Bracing or guying systems are designed to resist combined axial and bending action of the reinforcement cage subject to lateral loads. Appropriate design guidance should be sought from appropriate reference for steel beam-columns. The effective length for design is the longitudinal distance between support points or the length of the cage if only a single tier of bracing is used. All of the longitudinal bars can be used to resist the bending moment but only 25% of the vertical bars should be used for transfer of axial loads from a brace or guy cable (assuming four braces or guys).

#### 5.1.4.1Design of Bracing Support Systems

Bracing (tension and compression) support systems are appropriate for cage less than 6m tall with H/D > 8. A minimum of two strut braces placed 90 degrees apart is recommended. Struts must be mechanically attached to reinforcement cage and anchor blocks and locked from expansion or contraction if telescoping poles are used. They should be lagged or bolted to the reinforcement cage at two-thirds the height or higher. At the height of the brace, a horizontal "wagon wheel" element is recommended for transferring lateral loads through the cage.

Braces should be mechanically attached to the longitudinal bars or, if used, to the larger pick-up bars. Fixed strut braces should be installed at an angle to the horizontal not greater than 45 degrees. Appropriate factors of safety should be used in designing the brace system. A compressive/tensile force factor of safety of 1.5 is recommended.

#### 5.1.4.2Design of Guy Wire Support Systems

Numerous design considerations are required for guy wire systems. Based on the structural analysis and factors of safety, appropriate number and size of guy wires should be specified.

Note that not more than 25% of total longitudinal bars should be used to transfer axial loads from one guy cable. The pre-tension and/or cable drape should be specified as well which may require catenary analysis depending on the gauge of guy cable specified.

Guy wires should be placed symmetrically (i.e. opposite one another, in even numbers). Four cables separated 90 degrees from one another is a common configuration. Asymmetrical configurations are possible but may result in twisting of the cage due to torsional stress when cables are moved for the placement of formwork.

When reinforcement cages exceed 9m tall, multiple levels of guy wires are recommended. Spacing for multiple levels of guy wires is recommended at 6m with no more than 6m of unsupported length. Guy wires should be placed at the top of the cage if possible, but no lower than 2/3 of the cage height measured from the bottom. The multiple levels should all be in the same vertical plane for each guy wire group and can be attached to the same or multiple anchor blocks. Multiple levels of guy wires provide greater lateral support but also provide redundancy in the event that a higher or lower guy cable is removed or damaged.

As already stated, guy wires, when tensioned, introduce downward compressive force on the cage; guy wire angles need to be controlled. Guy wires are ideally 45 degrees inclined to the horizontal but not more than 60 degrees. Multiple levels of guy wires promote higher more desirable wire angles.

Cable pre-tension requirements should also be satisfied and this is determined by an allowable drape. The weight length of cable, and pretension force are used to determine the drape of the cable. Pre-tensioning will stretch out slack in the guy wires. The amount of pre-tensioning depends on the type of guy wires and the effective height of the guy wire location compared to the reinforcement cage. Applying a large pre-tension load will reduce the ability of the guy wire to absorb additional load before it reaches the breaking strength. A pre-tension load of 10-15% of the ultimate breaking strength of guy wires is recommended. The guy wire should not be designed up to its breaking strength and an appropriate factor of safety should be included to obtain an allowable strength value.

For long cables, or for cables requiring larger than normal pre-tension, design checks should be performed for thermal effects on guy wire stress. Periodic wind or other forces can also cause “galloping" guy cables, a situation that should be avoided.

Guy wires should be a minimum of 3/8” IWRC braided steel wire, EHC guy wire cable or equivalent. A factor of safety of 3.0 recommended.

### 5.1.4.3Design of Anchor Blocks

The design of anchor blocks is needed for both guy wire systems and braces. Based on the structural analysis, the size, number, and layout are determined. Anchor blocks can be standard construction elements such as jersey barriers or k-rails, or they can be reinforced concrete blocks with embedded steel anchor points for attachment to poles or guy cables. When possible, anchor blocks should be placed on level grade, although not all blocks for all cables need to be at the same grade. Surface water diversion plans for anchor blocks should be created to prevent erosion and undermining.

Anchor blocks should be designed to resist sliding and overturning. A minimum overturning factor of safety of 1.5 is suggested.

### 5.1.4.4Design of Internαl Bracing

The placement of internal braces is dependent upon the height of the cage, the diameter of the reinforcement cage and the experience of the fabricator. The use of internal braces varies in detail and location from one fabricator to another.

Two types of internal braces are commonly used in construction, X-braces and square braces. X-braces are normally made of 4 bars bent in a Z shape and welded to two inner rings at the ends of the bars. The braces are tied to the longitudinal bars and spaced at specified intervals along the length of the reinforcement cage. The X-braces have a single point in common in the centre of the brace where they are welded to each other. Unlike the X-braces, square braces are normally made of 8 bars and they have three points in common with adjacent bars, two of which are close to the ends and on in the centre of the brace where they are welded to each other.

The design of internal braces involves standard structural frame analysis techniques. Proper understanding of load path and reactions acting on the frame supports are needed if stability is relied on internal braces. Temporary support system designs should include proper placement of internal bracing at support and lift points of the reinforcement cage. Most reinforcement cages with a height to breadth ratio of greater than 8 and reinforcement ratios of 1 to 2 percent are susceptible to instability and collapse. **Table 5.1** and **Table 5.2** provide lateral stiffness estimates for cages with internal bracings and with longitudinal reinforcement ratios of 1% and 2% respectively.

**Table 5.1 – Estimated lateral stiffness (N/m) of reinforcement cages with internal braces (1% reinforcement ratio)**

<table>
<tr><th rowspan="4">Cage height (m)</th><th rowspan="4">Design wind pressure (kPa)</th><th rowspan="4">No. of internal bracings along cage height</th><th colspan="8">Cage height to breadth ratio</th></tr>
<tr><th colspan="4">8</th><th colspan="4">10</th></tr>
<tr><th colspan="4">Size of internal braces</th><th colspan="4">Size of internal braces</th></tr>
<tr><th>#8</th><th>#9</th><th>#10</th><th>#11</th><th>#8</th><th>#9</th><th>#10</th><th>#11</th></tr>
<tr><td>6</td><td>1.0</td><td>2</td><td rowspan="9">11.2</td><td rowspan="9">11.4</td><td rowspan="9">11.8</td><td rowspan="9">12.0</td><td rowspan="9">7.6</td><td rowspan="9">7.7</td><td rowspan="9">7.8</td><td rowspan="9">8.0</td></tr>
<tr><td>9</td><td>1.2</td><td>2</td></tr>
<tr><td>12</td><td>1.2</td><td>2</td></tr>
<tr><td>15</td><td>1.4</td><td>3</td></tr>
<tr><td>18</td><td>1.4</td><td>3</td></tr>
<tr><td>21</td><td>1.4</td><td>4</td></tr>
<tr><td>24</td><td>1.4</td><td>4</td></tr>
<tr><td>27</td><td>1.4</td><td>4</td></tr>
<tr><td>30</td><td>1.7</td><td>4</td></tr>
</table>

**Table 5.2 – Estimated lateral stiffness (N/m) of reinforcement cages with internal braces (2% reinforcement ratio)**

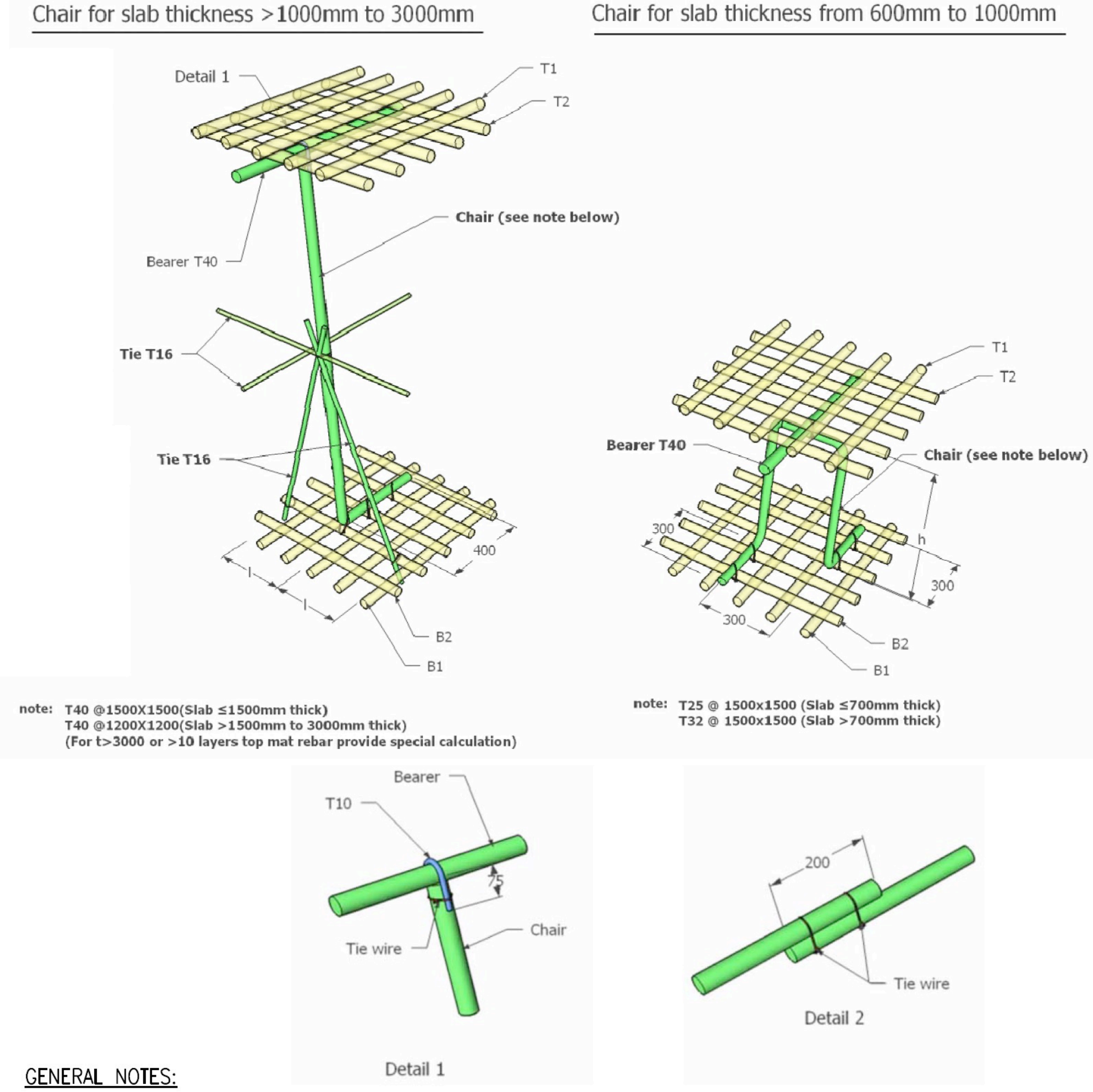
<table>
<tr><th rowspan="4">Cage height (m)</th><th rowspan="4">Design wind pressure (kPa)</th><th rowspan="4">No. of internal bracings along cage height</th><th colspan="8">Cage height to breadth ratio</th></tr>
<tr><th colspan="4">8</th><th colspan="4">10</th></tr>
<tr><th colspan="4">Size of internal braces</th><th colspan="4">Size of internal braces</th></tr>
<tr><th>#8</th><th>#9</th><th>#10</th><th>#11</th><th>#8</th><th>#9</th><th>#10</th><th>#11</th></tr>
<tr><td>6</td><td>1.0</td><td>2</td><td rowspan="9">14.5</td><td rowspan="9">15.1</td><td rowspan="9">16.2</td><td rowspan="9">17.2</td><td rowspan="9">10.2</td><td rowspan="9">10.5</td><td rowspan="9">11.0</td><td rowspan="9">11.5</td></tr>
<tr><td>9</td><td>1.2</td><td>2</td></tr>
<tr><td>12</td><td>1.2</td><td>2</td></tr>
<tr><td>15</td><td>1.4</td><td>3</td></tr>
<tr><td>18</td><td>1.4</td><td>3</td></tr>
<tr><td>21</td><td>1.4</td><td>4</td></tr>
<tr><td>24</td><td>1.4</td><td>4</td></tr>
<tr><td>27</td><td>1.4</td><td>4</td></tr>
<tr><td>30</td><td>1.7</td><td>4</td></tr>
</table>

### 5.1.4.5Spacing of Mats

In order to fix the final depth of the element the bars need to be spaced apart. With beam and column elements this is usually achieved with the links. For slab and wall elements specific chairs or spacers will be required.

Even with links providing the shape of the elements some bars may be supported only by the ties to the links rather than by the enclosure of links.

For slabs and foundation elements the chairs will need to be designed to allow the top mat to be accessed as a working platform. The size of chairs to support the upper mat will be a function of the chair spacing (which depends on the size and strength of the top mat) and the weight of the top mat combined with the access load. Typical details and design of supporting chairs are illustrated in **Figures 5.2 to 5.4** below.




GENERAL NOTES:

1. THE DRAWINGS ARE INTENDED TO ILLUSTRATE THE GENERAL PRINCIPLES OF THE REBAR SUPPORT IN THICK SLABS.
2. THE DRAWINGS ILLUSTRATE THE MINIMUM STANDARDS TO BE APPLIED. DRAWINGS SHALL BE DEVELOPED TO SUIT PARTICULAR GEOMETRY AT ANY PARTICULAR LOCATION FOR THE PROJECT.
3. PRIOR TO COMMENCEMENT OF THE REBAR FIXING, SITE RESPONSIBLE PERSON SHALL ENSURE THAT SHOP DRAWINGS ARE PROVIDED TO SHOW THE DETAILS AND LOCATIONS OF CHAIRS AND ANY OTHER SUPPORTS TO BE PROVIDED FOR SUPPORTING THE REBAR CAGES.

***Figure 5.2 – Typical details for support for rebar mats in heavy slabs and transfer plate (1 of 3)***

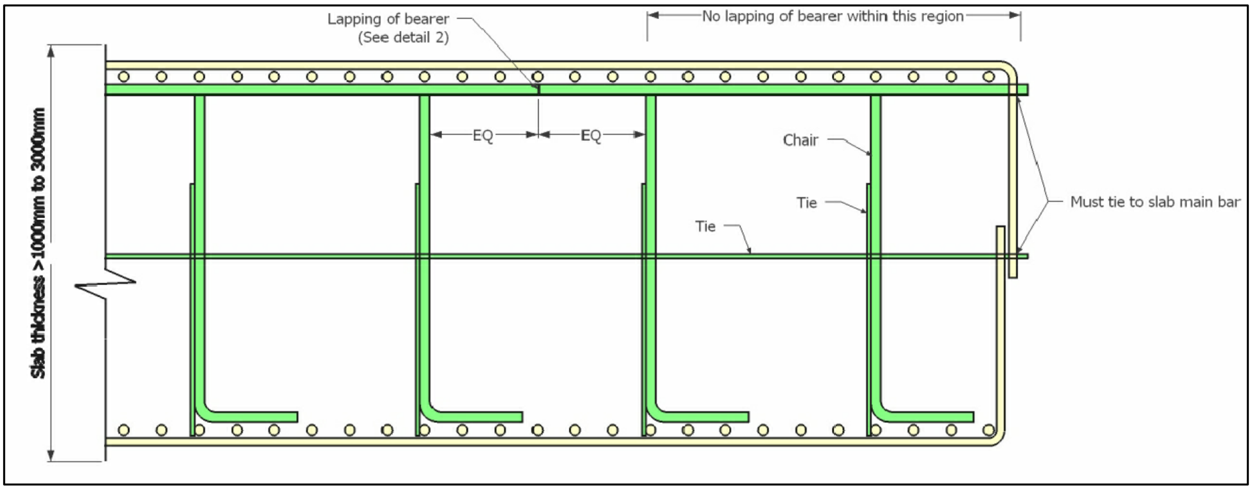



*Figure 5.3 – Typical details for support for rebar mats in heavy slabs and transfer plate (2 of 3)*

## Support Chair for Fixing of Thick Slab Top Reinforcement

| | | Bar dia. (mm) | Spacing (mm) | Kg/m$^2$ | Bar dia. (mm) | Spacing (mm) | Kg/m$^2$ | Bar dia. (mm) | Spacing (mm) | Kg/m$^2$ | Bar dia. (mm) | Spacing (mm) | Kg/m$^2$ | Bar dia. (mm) | Spacing (mm) | Kg/m$^2$ | Bar dia. (mm) | Spacing (mm) | Kg/m$^2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Max. Structure Thickness(mm) | | 600 | | | 600 | | | 700 | | | 700 | | | 700 | | | 800 | | |
| Top Bars | T1 | 32 | 125 | 51 | 40 | 150 | 66 | 32 | 150 | 42 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 |
| | T2 | 32 | 125 | 51 | 40 | 150 | 66 | 32 | 150 | 42 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 |
| | T3 | | | | | | | | | | | | | 32 | 150 | 42 | 20 | 150 | 16 |
| | T4 | | | | | | | | | | | | | 32 | 150 | 42 | 20 | 150 | 16 |
| | T5 | | | | | | | | | | | | | | | | | | |
| | T6 | | | | | | | | | | | | | | | | | | |
| | T7 | | | | | | | | | | | | | | | | | | |
| | T8 | | | | | | | | | | | | | | | | | | |
| | T9 | | | | | | | | | | | | | | | | | | |
| | T10 | | | | | | | | | | | | | | | | | | |
| | h (mm) | 322 | | | 290 | | | 422 | | | 390 | | | 262 | | | 410 | | |
| | Steel ratio of support chair (kg/m$^3$) | 15.1 | | | 15.0 | | | 13.5 | | | 13.3 | | | 12.7 | | | 14.0 | | |
| Support Chair | Estimated load per chair (2 legs, Kg) | 227 | | | 296 | | | 189 | | | 296 | | | 485 | | | 370 | | |
| | Inspection Rate (by Site Responsible Person) | As required, before fixing the top bars | | | | | | | | | | | | | | | Periodic, before fixing the top bars | | |

| | | Bar dia. (mm) | Spacing (mm) | Kg/m$^2$ | Bar dia. (mm) | Spacing (mm) | Kg/m$^2$ | Bar dia. (mm) | Spacing (mm) | Kg/m$^2$ | Bar dia. (mm) | Spacing (mm) | Kg/m$^2$ | Bar dia. (mm) | Spacing (mm) | Kg/m$^2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Max. Structure Thickness(mm) | | 800 | | | 800 | | | 1000 | | | 1000 | | | 1000 | | |
| Top Bars | T1 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 |
| | T2 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 |
| | T3 | 25 | 150 | 26 | 32 | 150 | 42 | 25 | 150 | 26 | 32 | 150 | 42 | 40 | 150 | 66 |
| | T4 | 25 | 150 | 26 | 32 | 150 | 42 | 25 | 150 | 26 | 32 | 150 | 42 | 40 | 150 | 66 |
| | T5 | | | | | | | | | | | | | | | |
| | T6 | | | | | | | | | | | | | | | |
| | T7 | | | | | | | | | | | | | | | |
| | T8 | | | | | | | | | | | | | | | |
| | T9 | | | | | | | | | | | | | | | |
| | T10 | | | | | | | | | | | | | | | |
| | h (mm) | 390 | | | 362 | | | 590 | | | 562 | | | 530 | | |
| | Steel ratio of support chair (kg/m$^3$) | 13.8 | | | 13.6 | | | 12.2 | | | 12.0 | | | 11.9 | | |
| Support Chair | Estimated load per chair (2 legs, Kg) | 412 | | | 485 | | | 412 | | | 485 | | | 592 | | |
| | Inspection Rate (by Site Responsible Person) | Periodic, before fixing the top bars | | | | | | | | | | | | | | |

| | | Bar dia. (mm) | Spacing (mm) | Kg/m$^2$ | Bar dia. (mm) | Spacing (mm) | Kg/m$^2$ | Bar dia. (mm) | Spacing (mm) | Kg/m$^2$ | Bar dia. (mm) | Spacing (mm) | Kg/m$^2$ | Bar dia. (mm) | Spacing (mm) | Kg/m$^2$ | Bar dia. (mm) | Spacing (mm) | Kg/m$^2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Max. Structure Thickness(mm) | | 1250 | | | 1250 | | | 1250 | | | 1500 | | | 1500 | | | 1500 | | |
| Top Bars | T1 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 |
| | T2 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 |
| | T3 | 25 | 150 | 26 | 32 | 150 | 42 | 40 | 150 | 66 | 25 | 150 | 26 | 32 | 150 | 42 | 40 | 150 | 66 |
| | T4 | 25 | 150 | 26 | 32 | 150 | 42 | 40 | 150 | 66 | 25 | 150 | 26 | 32 | 150 | 42 | 40 | 150 | 66 |
| | T5 | | | | | | | | | | | | | | | | | | |
| | T6 | | | | | | | | | | | | | | | | | | |
| | T7 | | | | | | | | | | | | | | | | | | |
| | T8 | | | | | | | | | | | | | | | | | | |
| | T9 | | | | | | | | | | | | | | | | | | |
| | T10 | | | | | | | | | | | | | | | | | | |
| | h (Clear/2, mm) | 420 | | | 406 | | | 390 | | | 545 | | | 531 | | | 515 | | |
| | l (S1/3, mm) | 500 | | | | | | | | | | | | | | | | | |
| | Steel ratio of support chair (kg/m$^3$) | 12.1 | | | 12.0 | | | 11.9 | | | 10.9 | | | 10.8 | | | 10.7 | | |
| Support Chair | Estimated load per chair (2 legs, Kg) | 412 | | | 485 | | | 592 | | | 412 | | | 485 | | | 592 | | |
| | Inspection Rate (by Site Responsible Person) | Alternate pour before fixing of top bars, sign off required | | | | | | | | | | | | | | | | | |

| | | Bar dia. (mm) | Spacing (mm) | Kg/m$^2$ | Bar dia. (mm) | Spacing (mm) | Kg/m$^2$ | Bar dia. (mm) | Spacing (mm) | Kg/m$^2$ | Bar dia. (mm) | Spacing (mm) | Kg/m$^2$ | Bar dia. (mm) | Spacing (mm) | Kg/m$^2$ | Bar dia. (mm) | Spacing (mm) | Kg/m$^2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Max. Structure Thickness(mm) | | 2000 | | | 2000 | | | 2500 | | | 2500 | | | 3000 | | | 3000 | | |
| Top Bars | T1 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 |
| | T2 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 |
| | T3 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 |
| | T4 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 |
| | T5 | 32 | 150 | 42 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 |
| | T6 | 32 | 150 | 42 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 |
| | T7 | | | | | | | 32 | 150 | 42 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 |
| | T8 | | | | | | | 32 | 150 | 42 | 40 | 150 | 66 | 40 | 150 | 66 | 40 | 150 | 66 |
| | T9 | | | | | | | | | | | | | 32 | 150 | 42 | 40 | 150 | 66 |
| | T10 | | | | | | | | | | | | | 32 | 150 | 42 | 40 | 150 | 66 |
| | h (Clear/2, mm) | 701 | | | 685 | | | 871 | | | 855 | | | 1041 | | | 1025 | | |
| | l (S1/3, mm) | 400 | | | | | | | | | | | | | | | | | |
| | Steel ratio of support chair (kg/m$^3$) | 12.6 | | | 12.4 | | | 11.1 | | | 11.0 | | | 10.2 | | | 10.1 | | |
| Support Chair | Estimated load per chair (2 legs, Kg) | 500 | | | 568 | | | 689 | | | 758 | | | 879 | | | 947 | | |
| | Inspection Rate (by Site Responsible Person) | Every time before fixing of top bars, sign off required | | | | | | | | | | | | | | | | | |

See note 3

Estimated load per chair = (66 + 66 + 66 + 66 + 66 + 66 + 42 + 42 ) x 1.2 x 1.2

(1.2m c/c both directions)

Notes:

1 Assumed concrete cover =75mm top & bottom.

2 Assumed same reinforcement for bottom rebars as top rebars in calculating the chair height.

3 The determination of support chair type shall base on thickness of the structure and the top bars to be supported. For example, if a pile cap with maximum thickness of 1500mm and top bars not more than 4 layers of T40 with rebar spacing not smaller than 150mm, "L-shape" support chair with spacing 1500mm each direction can be used.

4 The above table shows the minimum requirement of temporary support. User may add more supports or reduce the spacings of the supports as required to control the gravity deformation of the reinforcement during fixing.

*Figure 5.4 – Typical details for support for rebar mats in heavy slabs and transfer plate (3 of 3)*

Distribution steel running perpendicular to the lowest top mat bars should be provided as this prevents bars being suspended by tying wire and ensures all bars bear adequately onto the cover spacers. The standard chair (BS8666 shape code) relies on the strut action of the vertical legs. These are bi-axially bent by the shape of the chair.

The effective length of the strut shall be taken as 1.5 times the distance between the mats. **Table 5.3** and **Table 5.4** summarize the ultimate and working capacity of the chairs.

For maintaining the separation of mats in walls and thinner slabs, continuous wire chairs are useful. The edges of slabs and walls will need support close to the end of the wall or stop-end.

**Table 5.3 – Ultimate capacity of chair elements per leg - $P_{ult}$ (kN)**

(Based on effective length equal to 1.5 times mat spacing)

| Depth between mats (mm) | 250 | 500 | 750 | 1000 | 1250 | 1500 |
|---|---|---|---|---|---|---|
| H12 leg | 12.7 | 3.4 | X | X | X | X |
| H16 leg | 36.8 | 10.6 | 4.9 | X | X | X |
| H20 leg | 79.4 | 25.2 | 11.7 | 6.7 | X | X |
| H25 leg | Y | 59.1 | 28.0 | 16.1 | 10.5 | X |
| H32 leg | Y | Y | 76.4 | 44.0 | 28.5 | 19.9 |

Notes: X indicates an element that is too slender, Y indicates a dimension that is too small to bend

**Table 5.4 – Working capacity of chair elements – 2 legs (kN)**

(Based on Shape Code 98, A, C, D = 500mm, B to suit cage. Capacity is 2 x $P_{ult}$ / 1.5)

| Depth between mats (mm) | 250 | 500 | 750 | 1000 | 1250 | 1500 |
|---|---|---|---|---|---|---|
| H12 leg | 16.9 | 4.6 | X | X | X | X |
| H16 leg | 49.1 | 14.1 | 6.5 | X | X | X |
| H20 leg | 105.8 | 33.6 | 15.6 | 8.9 | X | X |
| H25 leg | Y | 78.8 | 37.3 | 21.5 | 14.0 | X |
| H32 leg | Y | Y | 101.9 | 58.7 | 38.0 | 26.5 |

Note 1: X indicates an element that is too slender, Y indicates a dimension that is too small to bend

Note 2: Dimension A to suit bending capacity of chair reinforcement under load applied from distribution reinforcement bar(s) (Typically 150mm-500mm)

### 5.1.4.6 Maintaining Shape

The main issue of reinforcement cage stability is in keeping the shape of the element. The stiffness of the element comes entirely from the connections between the bars and the links. As such the tying of the reinforcement becomes critical, particularly if the element is to be lifted.

Although outside the scope of this document, prefabricated pile and diaphragm wall cages often have shaped templates within the cage and bars are welded to these to provide some additional integrity to the cage.

### 5.1.4.7 Improved Fixity of Bars Within Cage

The requirements of BS 7973-2:2001 - Spacers and chairs for steel reinforcement and their specification, provides for stable cages in most circumstances. However, the use of additional ties at starter bars, lifting points and any other highly stressed areas is recommended. The use of welding or of 'bulldog' type clamps should be considered when the connection is highly stressed. Where slabs are heavily reinforced, very deep or have to support heavy construction loads then the vertical load capacity of the chairs should be checked.

### 5.1.4.8 Improved Spacing of Mats Within Cage

If sufficient chairs are provided the mats will be adequately spaced. Where there are large eccentricities or potentially high lateral loads providing larger/stronger chairs will stiffen the element.

### 5.1.4.9 Measures That Can Increase Stability

Supporting reinforcement often presents a number of practical problems such as finding suitable support points and the support obstructing the formwork. Various options are available which have advantages and disadvantages.

a) Install one face of the shutter ahead of reinforcement fixing to act as a support. Adequate support to the shutter shall be properly designed and provided to prevent from reinforcement cage pulling it over.
b) Install independent props
c) Install guy ropes
d) Cast support posts within the wall projecting from the kicker.
e) Adapt the access scaffolding used to erect it to have sufficient capacity to support the reinforcement.
f) Install additional longitudinal bars to prevent racking, or additional spacer bars tied to the horizontal lacers to prevent flexure.

### 5.1.4.10 Method of Assessing Stability Requirements

Prefabricated reinforcement cages require special consideration to ensure that the cage remains stable during fixing.

Single face reinforcement mats are particularly vulnerable to instability and temporary measures may be necessary to support the mat depending upon its height above kicker level and the spacing and diameter of the vertical bars.

Double faced cages may also require the addition of spacer bars to connect the individual faces of reinforcement together thereby improving the rigidity of the cage. Double face reinforcement above a certain height may also require additional external temporary measures to support the cage depending upon the spacing and diameter of the bars.

The construction sequence and method of working should ensure that the formwork closely follows the fixing of reinforcement. Specific measures should be undertaken, to ensure that stability of reinforcement is maintained, in the section beyond a previously concreted wall or pier.

Wherever possible the fixing of reinforcement should generally commence or terminate at corners or return walls which will normally provide additional rigidity to the cage. If external temporary measures are considered necessary, their form should take into account the method of supporting the formwork fixed at a later stage.

### 5.1.4.11 Tying Reinforcement Cage

Nodes where one rebar overlaps or crosses another in the same plane should be connected using single or multiple strands of tying wire that is twisted tight to hold the node in place.

If the tying wire is not twisted sufficiently tight then the bars may slip or move; but if the wire is twisted too tight it can be strained to leave little working margin leading to failure under little additional load. Wire ties can be easily overstressed if the twisting action is used to pull rebar together to close up gaps. Kinked, nicked or corroded tie wire will also result in weak ties.

Ties are normally formed using 1.6mm diameter (16 SWG) wire or 1.2mm diameter (18 SWG) stainless steel wire to one of the details below.

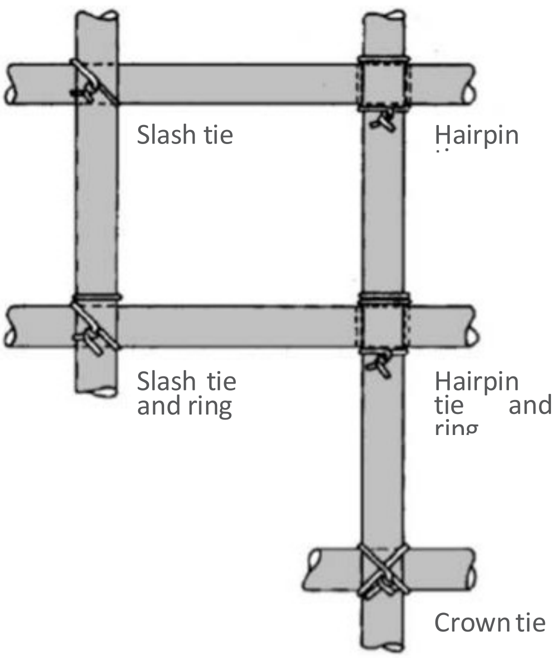



***Figure 5.5 – Typical tie patterns***

It should be noted that the strength of reinforcement ties can vary considerably. The fixing of reinforcement is mainly carried out using hand tools and there is inevitably a large variation in the techniques used by steel fixers.

Where there are multiple layers of reinforcement (3+), the ties should be wrapped around the adjacent bars, for example, layer 1 to layer 2 and layer 2 to layer 3. Wrapping ties around multiple layers increases the stretch in the wire and reduces the capacity of the ties.

The strength of ties can vary depending on the configuration of the wire and the tension in the wire when the tie is made. The length and number of twists will also affect the capacity of the tie. Most ties are still made by hand however there are machines available which are constantly being improved. It is good practice to assume that half of the ties are loose or broken in the design and ensure that there is sufficient redundancy to make sure that every bar is still secure. It is important to specify tie patterns, minimum numbers of ties and maximum tie centres.

Bars may be clamped together at laps to achieve a higher strength joint. Bars may also be welded in compliance with the British Standard for the welding of reinforcing BS EN ISO 17660-2 2006.

Examples of ties, clamps and welded splice connections are illustrated below.

***Plate 5.1 – (Left) Single slash tie (Right) Double slash tie***

***Plate 5.2 – Example of clamps***

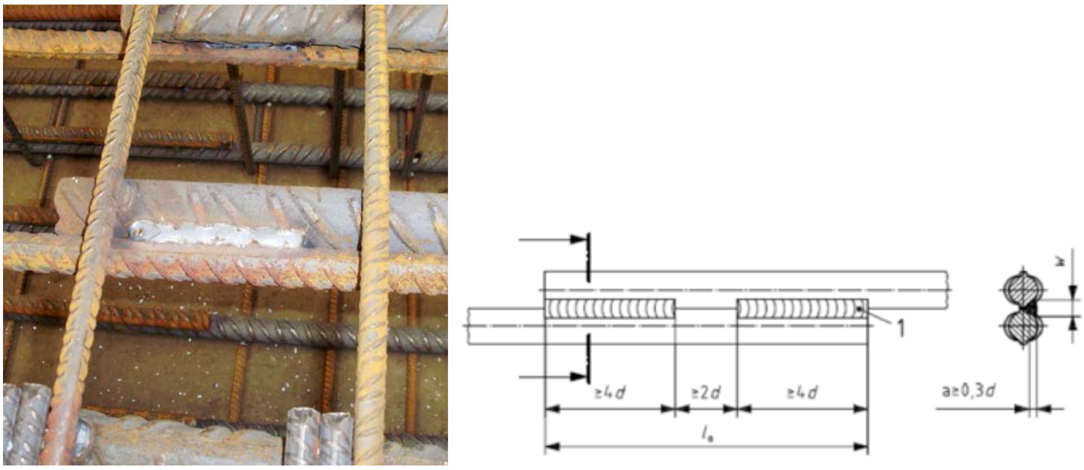



***Plate 5.3 – Example of welded splice detail***

### 5.1.5. Installation

Beyond the design of the temporary support system, it is also incumbent on the construction engineer to specify how to install it. This includes the staging, movement and installation sequence.

For reinforcement cages supported by guy wires, the following general procedure is recommended:

1) Set the reinforcement cage with crane;
2) Attach guy cables to anchor blocks and reinforcement cage. Guy cables should be attached to both longitudinal bars and hoops;
3) Remove slack from the cables using 2-4 kN of tension (recommend 10% of the published ultimate strength of the cage). Verify the tension using a cable tension meter;
4) Slack the crane and rigging (but not the guy wires) and verify cage is stable by shaking/bumping/pushing;
5) If cage shows no indications of instability, remove the crane. If unstable, leave the crane attached until more bracing/reinforcement can be installed as per engineer;
6) Install reflective tape, ribbon, or flags on guy wire system to improve visibility for crane operators and other crews.

The engineer should further state inspection requirements for checking the support system and verifying its integrity after lifting, installation and for the entire duration of the temporary condition. It is assumed that the entire temporary support system design and installation, inspection, and modification procedure will be specified prior to any rigging or lifting operations and prior to any work on or around the cage can begin.

## 5.2. Rigging and Lifting

Detailed rigging and lifting requirements are not provided in this document but it is obvious that a proper lifting plan should be developed for all reinforcement cage lifting operations. It is important to properly support reinforcement cages during lifting to avoid excessive bending of the reinforcement cage and distorting it permanently. All lifts must be designed such that the crane will not exceed its configured chart capacity at any point during the lift operation. Once positioned in an upright position, the top of the cage is to be within a specified tolerance of elevations shown in the drawing plans. Lifting plan should also comprise the implementation of a risk assessment procedure, the selection of safe and proper equipment as well as the assignment of competent personnel.

Typical cage lifting processes include preparing the cage so it can be rigged and lifted, rigging the cage (gripping), hoisting the cage for placement, walking the cage for placement and placing the load where a boom tip is swung to a vertical point above the placement point to lower the reinforcement cage. Regardless of the size of cage being lifted, an analysis should be performed by an engineer with relevant experience.

Under no circumstances should the crane be released until the temporary support system is installed and verified stable according to the installation procedure above.

The followings should be considered when lifting prefabricated reinforcement cage:

a) The weight of the cage should be established based on the reinforcement bending schedule.
b) The position of the lifting points should be suitably designed to ensure the cage does not deform excessively with lifting beams used to ensure loads are distributed evenly and at an angle perpendicular to the bars to be lifted. Evenly distributed loading on the cage will depend on lifting beam stiffness, spacing of attachments and sling stiffness and length. Double ties shall be used for cages that are to be lifted or handled.
c) Many reinforcement cages are unusual shapes and the centre of gravity becomes difficult to calculate. As with all lifts, the cage will move or rotate as the load is taken up until the centre of gravity of the lift is directly below the point of suspension (the crane hook). It is important to establish a set of lifting points and lifting equipment that facilitates any required movement.
d) Consideration should be given to positioning lifting points on the lowest bars so as to minimise the number of wire ties working in tension during the lift.
e) Cages should be re-inspected after each lift if moving several times. Ties may have stretched if the cage has deflected significantly during the previous lift. It is advisable not to double or triple handle cages where practicable.
f) Small pile-caps are often prefabricated, and these are often lifted by plant travelling on rough ground. Particular attention shall be paid to failure by the spacing of the upper and lower mats not being maintained.
g) Prefabricated cages should not be lifted over the heads of personnel.

If possible, the cage should be fixed in the same alignment as it will be eventually placed so that no tilting or turning is required. This can involve creating the cage in a jig that is set at the correct angle.

Some cages such as walls may need to be fixed on their side and then tilted through 90° when they are picked up. Tilting a cage will be critical both for the internal strength of the cage and for the lifting equipment (including the lifting points). Large wall cage lifts are often undertaken as tandem lifts so that the cage is not touching the ground when it is rotated but the rigging and execution of such lifts is complex and involves lifting equipment that accommodates the change in lifting angles (this can involve pulleys to allow rotation). Sliding of the cage along the ground as it is tilted should be avoided and prevented with ties if necessary.

The design of lifting points to facilitate rotation in reinforcement cages is very complex and best avoided if possible, or it shall be designed.

## 5.3. Change to the Support System

It is a common practice to use multiple levels of guy wires, which are typically greater than 12m in height. However multiple levels of guy wires may be in conflict with the forms and a few wires may have to be temporarily removed to accommodate the forms. Most accidents are attributable to this stage of construction. If such a construction sequence is to be implemented, the stability of reinforcement cages during the partial removal of some of the guy wires should be assessed and the remaining guy wires should be able to withstand the temporary loads for which the cage was designed.

The stability of the reinforcement cage should also be checked before all temporary support system are released from cranes or lifting device. This will ensure that the temporary systems are secured and the reinforcement cage will not be inadvertently displaced after release. It is recommended that cage deflection limits be set to ensure stability of the cages before releasing cranes or lifting devices.

***Formwork Procedure***

1) Install the first level of formwork up to the first level of guy wire.
2) With Crane attached to the cage and rigging taught move the guy wires, one-at-a-time from the reinforcement cage to the form.
3) Re-tension guy wires.
4) Install formwork above guy wires.

# 6. CHECKLIST

The chapter outlines the recommendations and guidelines applicable to field personnel based on the process and engineering background presented in the previous Chapters.

The followings present high-level checklists that are intended to provide informed guidance and should be useful for verifying each stage of the reinforcement cage design and construction process.

## 6.1. Permanent Works Design Checklist

**Table 6.1 – Permanent Works Design Checklist**

| Permanent Works Design Checklist | | |
|---|---|---|
| **Items** | **Y/N** | **Remarks** |
| 1) Have design alternatives been considered that allow for smaller cages or allowances for segmental construction? | | |
| 2) Was additional longitudinal reinforcement or stronger ties considered to promote greater stiffness for the cage's temporary condition? | | |
| 3) Has the fabricator or rebar sub-contractor detailed internal braces and will they provide sufficient stiffness? | | |
| 4) Was a constructability review done in consultation with the general contractor to identify potential conflicts with staging lifting, or supporting of the cage on site? | | |
| Completed by: | | Signed off by Temporary Works Designer |

## 6.2. Fabrication Checklist

**Table 6.2 – Fabrication Checklist**

| Fabrication Checklist | | |
|---|---|---|
| **Items** | **Y/N** | **Remarks** |
| 1) Tie wire connections shall use not smaller than 15 SWG tie wire made of soft annealed black steel with a minimum ultimate strength of 275MPa. | | |
| 2) At least four vertical bars forming a square shall be tied at every intersection with at least a double tie wire connection. The strength of these connections shall be adequate for cage pick-up. | | |

| Fabrication Checklist | | |
|---|---|---|
| 3) At a maximum of 2.4m increments, template hoops shall be tied at every intersection with at least a wrap and saddle tie wire connection. | | |
| 4) At least 20% of the remaining reinforcement intersections shall be tied with single tie wire connections. The connections shall be staggered from adjacent connections. | | |
| 5) Check that a proper temporary works design (e.g. weight of cage, overturning FOS, adequate base support for the cage, ) is in place. | | |
| 6) Check that proper shop drawings showing details of reinforcement cage and supporting system (e.g. props, guy wires, chairs, bracing, U-bolts, connection at base, etc.) according the temporary works design is in place. | | |
| 7) Types, frequency and spacing of ties comply with the design; ties are correctly tensioned; sufficient twist projects from the tie | | |
| 8) Shape codes, size, orientation, position, spacing, dimension and layering of bars are correct; no unauthorised cutting and heating of bars has taken place; bars are bent using correct formers | | |
| 9) Splices have lap length and appropriate ties; appropriate lap stagger has been employed | | |
| 10) Cage has retained the design shape; reinforcement has not been kinked or bent out of shape; physical dimensions of the cage comply with the design | | |
| 11) Mechanical couplers are fully engaged and tightened; mechanical grips / connectors are installed in accordance with manufactures guidelines and are tightened to the correct torque; welding is carried out by an appropriately skilled welder to an approved procedure; welds comply with the design and are of appropriate length and size | | |
| Completed by: | | Signed off by Temporary Works Designer |

## 6.3. Pre-Lift and Lift Checklist

The construction engineer working for the general contractor and the superintendent and foreman of the erection crew will perform the pre-lift and lift-checklist. The following checklist is recommended two weeks prior to a cage lift.

**Table 6.3 – Pre-lift and Lift Checklist (Two Weeks prior to Cage Lift)**

| Pre-lift and Lift Checklist (Two Weeks prior to Cage Lift) | | |
|---|---|---|
| **Items** | **Y/N** | **Remarks** |
| 1) Review access to the job site and rigging area. Verify the bracing pattern for pipes (tremies) for pouring. | | |
| 2) Discuss hoisting information (weights, heights and other dimensions) including allowable lengths for charging, if required. | | |
| 3) Discuss crane (capacity, reach, and radius) with lifting crew, foreman, and superintendent. | | |
| 4) Review and discuss hazards, (underground, overhead electrical lines, reach concerns.) | | |
| 5) Have a copy of and review pre-planning plan. | | |
| 6) Have there been any changes to the drawings on site since the initial detailing plan was completed? | | |
| 7) What is being used to do the lifting? Crane? Forklift? | | |
| 8) What size of crane or forklift will be required? | | |
| 9) What access is available for crane or forklift? Is it adequate? | | |
| 10) Check weights of lifts; is it the same as your pre-plan procedure? | | |
| 11) What are your factors of safety to crane, rigging? | | |
| 12) What is the dowel pattern? Are the dowels the correct height? Are they in the correct location? | | |
| 13) What rigging are you going to use? What rigging do you have? | | |
| 14) Check size of rigging. Do you require a strong back or spreader? | | |
| 15) What rigging blocks and/or special rigging are required? (Snatch blocks, shackles) | | |
| 16) Do you need a rigging plan or is it a standard or typical lift for this project? | | |
| 17) Have you inspected the rigging? | | |
| 18) If guying or bracing is required, do you have a written plan? Who is going to supply? | | |
| 19) Who will be on the crew doing this work, what is their experience, have they done this type of work before? | | |
| 20) Ask for different opinions on pick points. | | |
| 21) Do you have all the information needed or are you missing anything? | | |
| 22) Review your plan with another foreman or supervisor. | | |

| Pre-lift and Lift Checklist (Two Weeks prior to Cage Lift) | | |
|---|---|---|
| 23) Are there any flares to be built on the cage, will they be done in the yard or field? | | |
| 24) Obtain guying procedure from Contractor or Construction Engineer whichever applies. | | |
| 25) Is the guying procedure appropriate for this cage? Who is going to supply and install? | | |
| 26) Is it engineered and stamped? | | |
| 27) Carefully review guying procedure. | | |
| 28) Is there proper truck access? | | |
| 29) Is there room to off-load cage from truck to ground? | | |
| 30) Are you lifting off the trailer? | | |
| 31) Do you need a crane with a main line and a whip line or 2 cranes? | | |
| 32) Is boom, main line, whip line & cage going to line up when tripping cage? | | |
| 33) Have someone your level or higher to talk over the hoisting plan with. | | |
| 34) Compare each other plans. | | |
| 35) Get together to review each other plans. | | |
| 36) Look for the following: things that are the same, things that are different discuss the differences. Make drawings with the necessary changes. Agree on the best hoisting plan. | | |
| 37) Start drawing the hoisting plan you agree on. | | |
| 38) On the drawing, provide the following information: length of cage, breadth of cage, weight of cage, locations and loads at the pick points, etc. | | |
| 39) Start planning rigging; discuss the safety factors you want to use. | | |
| 40) Start with the strong back or spreader beam, shackles, skoocums' (snatch blocks, shackles.) | | |
| 41) Running line, wire rope length sizes? Double check jewell out (i.e. rigging fits as it runs through skoocums or snatch block as cage is tripped. Check angle for right size) | | |
| 42) Chokers nylons or wire rope (length and sizes.) | | |
| 43) Back up bars. What back up bars do you need? | | |
| 44) Check bracing within the cage, is it sufficient? | | |
| 45) Is a Rat slab going to be needed for soil conditions? | | |

| Pre-lift and Lift Checklist (Two Weeks prior to Cage Lift) | | |
|---|---|---|
| 46) Does contractor need crane packs or metal plate for ground stabilization? | | |
| 47) Make sure picking bars are tied solid. | | |
| 48) Top few hoops above pick point should be tied solid. | | |
| 49) Will spreader bar fit onto hook of crane? | | |
| 50) Will running line rigging fit on hook? | | |
| 51) On single barrel cage added brace bars wrapped around the outside of the cage approximately 4.5m up to keep cage from cork screwing down (depending on size of verticals.) | | |
| 52) Ensure additional measures are considered if there is abnormal high consequence should a failure occur. | | |
| Completed by: | | Signed off by Temporary Works Designer |

The following checklist is recommended before the erection work.

**Table 6.4 – Pre-lift and Lift Checklist (Before Erection)**

| Pre-lift and Lift Checklist (Before Erection) | | |
|---|---|---|
| **Items** | **Y/N** | **Remarks** |
| 1) Have you completed a Job Hazard Analysis? | | |
| 2) Establish who will direct the crane operator; determine if hand signals or radio will be used to communicate. | | |
| 3) Have all guy lines & braces (if required) been installed on cage prior to erection? Ensure guy lines & braces are easily accessible without the need to climb the cage. Check cable clamps. | | |
| 4) Notify contractor and other subs that all guying & bracing only to be removed by Harris personnel. Have guying and or bracing check off sheet on site. | | |
| 5) Foreman to inspect bracing and guy lines to ensue materials are good. | | |
| 6) Is fall protection required? If so, is there a procedure in place? Are there other methods available (i.e. man baskets, genie lifts, scaffolding, etc?) | | |
| 7) Are there other trades working in the vicinity of the erection & if so, ensure that adequate warning is given of the impending hazard. When picking cage all personnel need to stay at least the | | |

| Pre-lift and Lift Checklist (Before Erection) | | |
|---|---|---|
| length of the cage away, except for the signal person & persons on the tag lines. Foreman to check each cable clamp. | | |
| 8) Rig cage to ensure all hoisting rigging can be removed without the need to climb the cage. Alternately, climb only after a foreman confirms that all guying & bracing is complete and cage is safe to disconnect rigging. | | |
| 9) Establish if tag lines need to be used and if so, that the person holding them has been properly trained. (Where to go in case of emergency.) | | |
| 10) If cage is going to be secured to formwork, ensure that the formwork has been designed to support the additional weight of the cage. In addition, review formwork details to ensure that there are means of tying off the cage. | | |
| 11) Inspect the cage to be flown to ensure no loose verts or untied pieces; Ensure cage is adequately tied to carry weight of other ties or verts. | | |
| 12) Ensure no one stands below cage as its being flown throughout the job site. | | |
| 13) Make good all dowels in preparation of accepting cage. | | |
| 14) Have a tail-gate meeting with the crew responsible for rigging, including crane operator and contractor's rigger (if applicable) to review all actions and hazards just prior to erection operation commences, include a written sign off sheet. | | |
| 15) Does everyone on the erection crew agree with the plan? If YES - proceed, If NO - resolve the differences before beginning work. | | |
| 16) Install all chairs or spacers on the cage prior to erection to prevent the need to climb the cage or formwork after the cage is erected. Alternately, climb only after a foreman confirms that all guying & bracing is complete and cage is safe to disconnect rigging. | | |
| 17) All guying & bracing to be adequately identified with reflective tape or flags at appropriate heights to make highly visible to crane operators, mobile equipment operators and personnel. | | |
| 18) Tie all the right angles on the bottom of footing solid. | | |
| 19) Check any impact on adjacent slope, retaining wall, temporary platform, scaffolding, etc. | | |
| 20) Ensure working condition is appropriate (e.g. even ground, firm ground, etc.), and necessary measures are implemented to ensure safe execution of reinforcement cage fixing. | | |
| 21) Ensure stockpiling location of reinforcement cage is in strict accordance with the loading key plan | | |

| Pre-lift and Lift Checklist (Before Erection) | | |
|---|---|---|
| 22) Ensure all workers are fully briefed about all key requirements. | | |
| 23) Check and ensure the reinforcement cage complies with the defined lifting and supporting requirements. | | |
| 24) Check and ensure that the reinforcement cage complies with all requirements related to the supporting system (e.g. props, guy wires, chairs, bracing, U-bolts, connection at base, etc.) | | |
| 25) Check if there is any slab starters or other bars (corbels, etc.) projecting horizontally resulting in eccentric loads, and ensure they are sufficient to take the load of the reinforcement cage and concreting. | | |
| 26) Any modifications that are necessary to enable bars to be fixed have been approved by the TWD and Bar Fixing Foreman. | | |
| 27) Any distress to the cages or failures of ties should be reported to the TWC. | | |
| 28) When lifting, a lift plan is in place and complied with. | | |
| 29) Appropriate lifting beams, shackles and slings are used in accordance with the lift plan and temporary works design. | | |
| 30) A post lift inspection should be carried out, with any loose or failed tie wires replaced. | | |
| Completed by: | | Signed off by Temporary Works Designer |

Finally, the on the day of the erection work, the following summary checklist is recommended.

**Table 6.5 – Pre-lift and Lift Checklist (On the Day of Erection)**

| Pre-lift and Lift Checklist (On the Day of Erection) | | |
|---|---|---|
| **Items** | **Y/N** | **Remarks** |
| 1) Know the setup of the cranes | | |
| 2) Know the effect the hoist has on the crane | | |
| 3) Know where to look when hoisting, watch for the unknown - all eyes should be watching. | | |
| 4) Watch for side loading | | |
| 5) Watch for non-plumb vertical lines. | | |
| 6) Watch for line and sheave problems. | | |
| 7) Watch and understand boom deflections | | |

| Pre-lift and Lift Checklist (On the Day of Erection) | | |
|---|---|---|
| 8) Watch for cage trip problems. | | |
| 9) Special rigging training by a wire rope manufacturer, 3 classes on jobsite training required. | | |
| 10) On heavy picks a person should be watching the back side of the crane to make sure it is not raising up. | | |
| 11) If we are using the contractor's spreader bar, make sure it is certified before using | | |
| 12) Check and ensure that the base of the cage is fixed to a structure which is stable and sufficient to hold the cage. | | |
| 13) Check and ensure that measures are implemented to prevent any loose rebar from hitting people nearby during lifting, stockpiling and fixing | | |
| Completed by: | | Signed off by Temporary Works Designer |

## 6.4. Temporary Condition Checklist

The cage should be released from its guy wires:

1) Only when necessary for the placement/movement of formwork,
2) In symmetrical pairs only to keep the cage in static equilibrium,
3) For a minimum amount of time only and with extra care for knocking or bumping an unsupported cage.

The following additional checking are recommended.

**Table 6.6 – Temporary Condition Checklist**

| Temporary Condition Checklist | | |
|---|---|---|
| **Items** | **Y/N** | **Remarks** |
| 1) Tie off bottom of cage to dowel rebar as determined during pre-planning. Alternately, are bottom of cage right angles secured to bottom mat or support frame as determined during pre-planning? | | |
| 2) Ensure cage is not released from crane until all bracing and j or guy lines (if applicable) are installed. Foreman to inspect cage and/or bracing or guying and complete a check list for all cages set in a day and record on sign off sheet. Turn in copy of check off to general contractor if required. | | |

| Temporary Condition Checklist | | |
|---|---|---|
| 3) Instruct General Contractor and other trades not to touch bracing and/or guy lines. | | |
| 4) Foreman to check cable clamps or braces. | | |
| Completed by: | | Signed off by Temporary Works Designer |

## 6.5. Permanent Condition Checklist

The permanent condition is achieved when all concrete is poured and sufficiently cured and all formwork is removed from the cage. The following recommendations are made about the permanent condition.

**Table 6.7 – Permanent Condition Checklist**

| Permanent Condition Checklist | | |
|---|---|---|
| **Items** | **Y/N** | **Remarks** |
| 1) Have the guys or temporary supports been moved or removed in a manner inconsistent with the temporary support plan? If so, document. | | |
| 2) Has all rigging and support hardware been removed and inspected for damage? | | |
| 3) Have the support systems of adjacent or nearby cages been affected by the removal of this cages supports? | | |
| Completed by: | | Signed off by Temporary Works Designer |

# 7. REFERENCES


1) BS5975 Code of Practice for Temporary Works Procedures and the Permissible Stress Design of Falseworks

2) BS7973–1:2001 Spacers and chairs for steel reinforcement and their specification. Product performance requirements

3) BS7973–2:2001 Spacers and chairs for steel reinforcement and their specification. Fixing and application of spacers and chairs and tying of reinforcement

4) Construction Industry Council – Guidelines on Fabrication of Reinforcement Cages of Bored Piles

5) Control and Management of Temporary Works, Temporary Works Forum Hong Kong

6) Industry Guidance for Designers, Construction Industry Advisory Committee

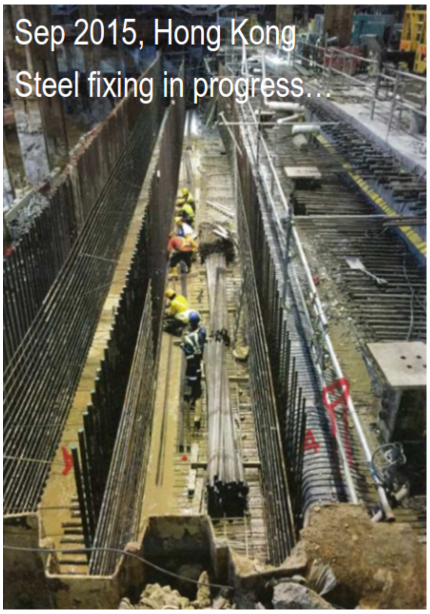
7) Occupational Safety & Health Council (OSHC), Environment, Transport and Works Bureau (ETWB) and Hong Kong Housing Authority (HKHA) – The Construction Design and Management

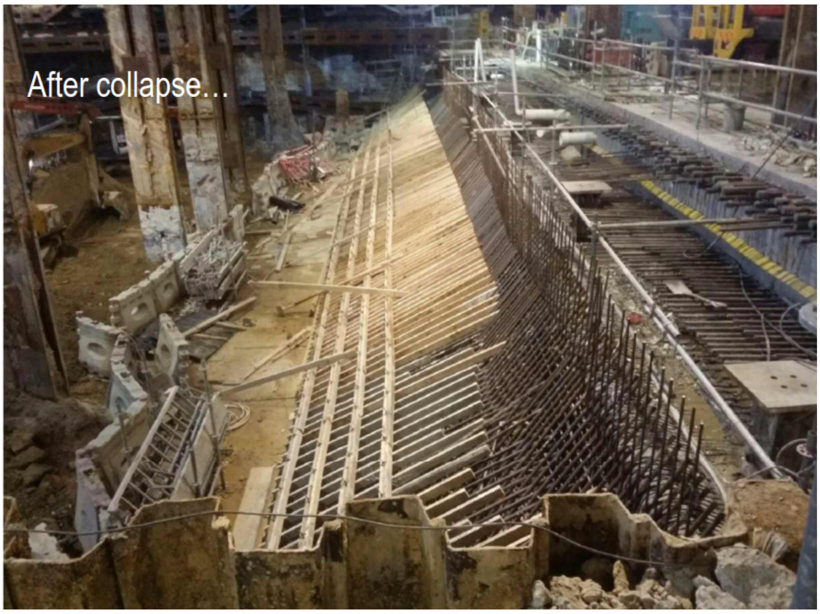
8) Reinforcement cage Construction and Safety, Best Practices, Construction Institute of the American Society of Civil Engineering

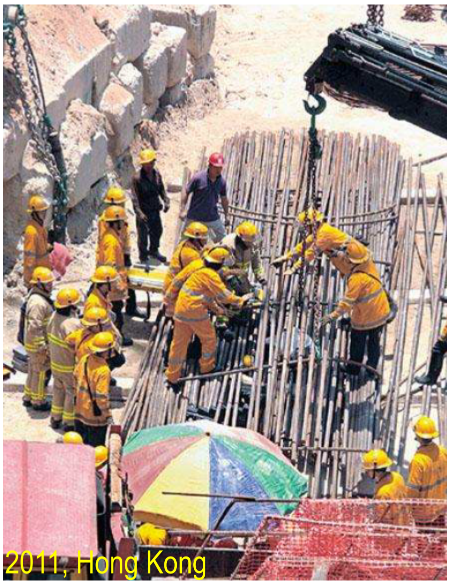
9) Steel Construction Manual, American Institute of Steel Construction

10) The Construction Design and Management, Occupational Safety & Health Council (OSHC), Environment, Transport and Works Bureau (ETWB) and Hong Kong Housing Authority (HKHA)

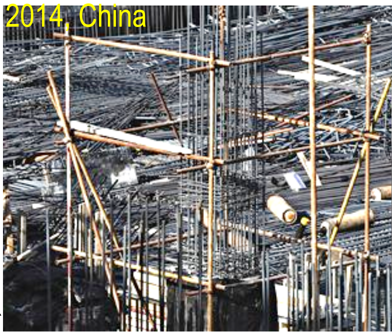
# Appendix A – Cage Collapse Examples

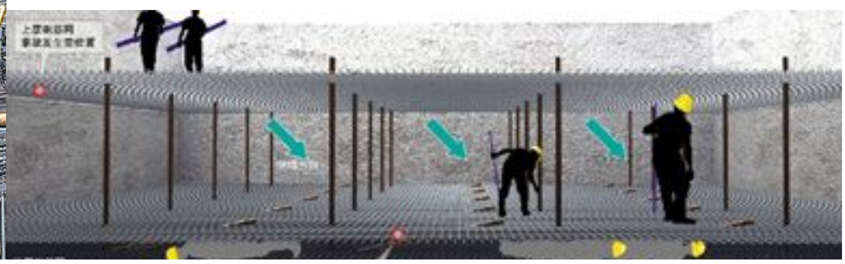

Sep 2015, Hong Kong
Steel fixing in progress…


After collapse…


2011, Hong Kong


2012, Taiwan


2014, China



Collapse during transportation

# Appendix B – Good Practice Examples

**Example 1**

The following sequence of photographs shows the key stages in the fixing, lifting transporting and placing of some large reinforcement cages weighing approximately 17t each.

**Plate B1 – Initial fixing in an offsite jig**

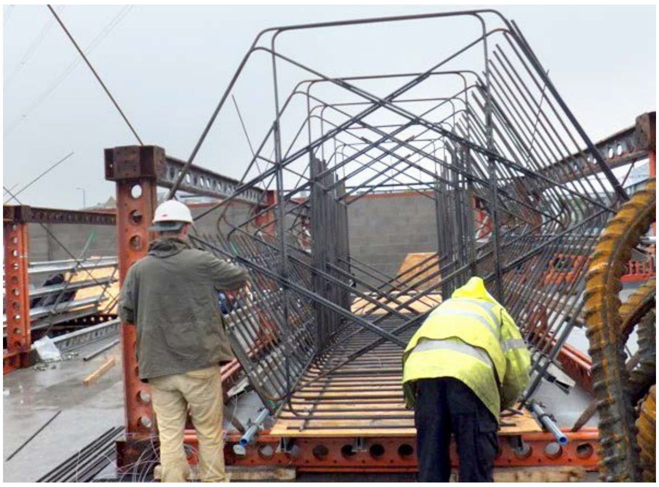


**Plate B2 – Opposite end of jig showing alignment rails**

**Plate B3 – Template welded to end of cage facilitates alignment of tensioning ducts (small lugs are not lifting eyes)**

**Plate B4 – Fabricated support near rear of cage. The cage has been constructed rotated to allow the supports to be fixed**

**Plate B5 – Detail of welding lugs fixing the template to the front of the cage**

**Plate B6 – Cage rotated using appropriate lifting equipment**

**Plate B7 – Cage lifted into position**

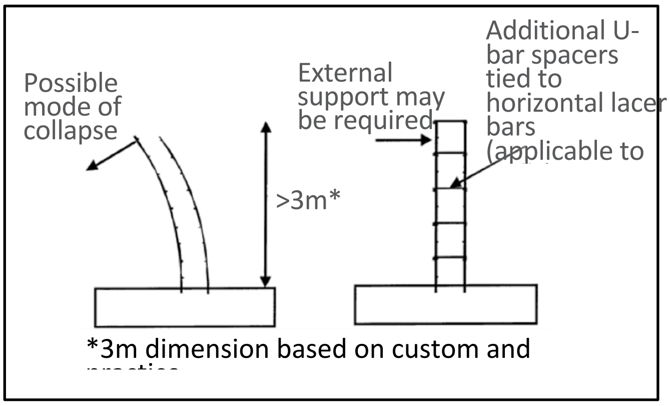



**Plate B8 – Elevation on wall or column showing bending of cage and additional spacer bars to provide stability**

**Example 2**

The following sequence of photographs shows details of support posts cast in to the base slab providing lateral stability to the reinforcement. This solution required permission from the permanent works designer.


**Plate B9 – Fabricated support posts fixed down to designed thickening in structural blinding**

**Plate B10 – Wall starter bars installed and fixed to structural steel. Additional structural lacer bars fixed at top of wall to distribute loads back to the post**

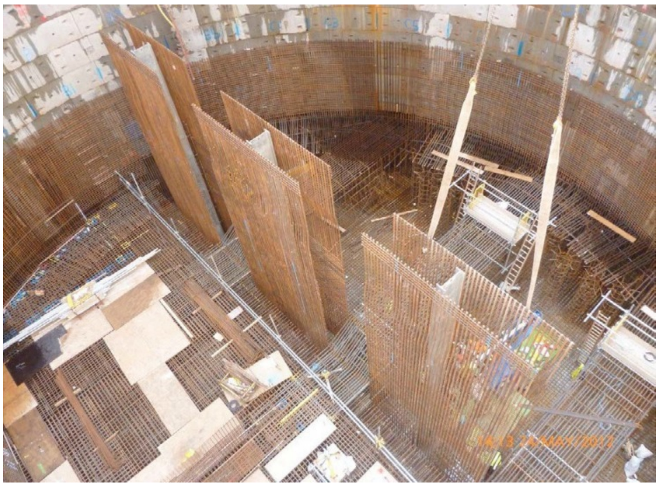


**Plate B11 – Prefabricated wall starter bars lifted into position and held in position with crane whilst being fixed to structural steel**

**Plate B12 – Wall starter bars installed in preparation for base slab pour**