BCA BE Seminar 2022
Buildings: What Can Go Wrong

Lessons Learnt from Structural Failures

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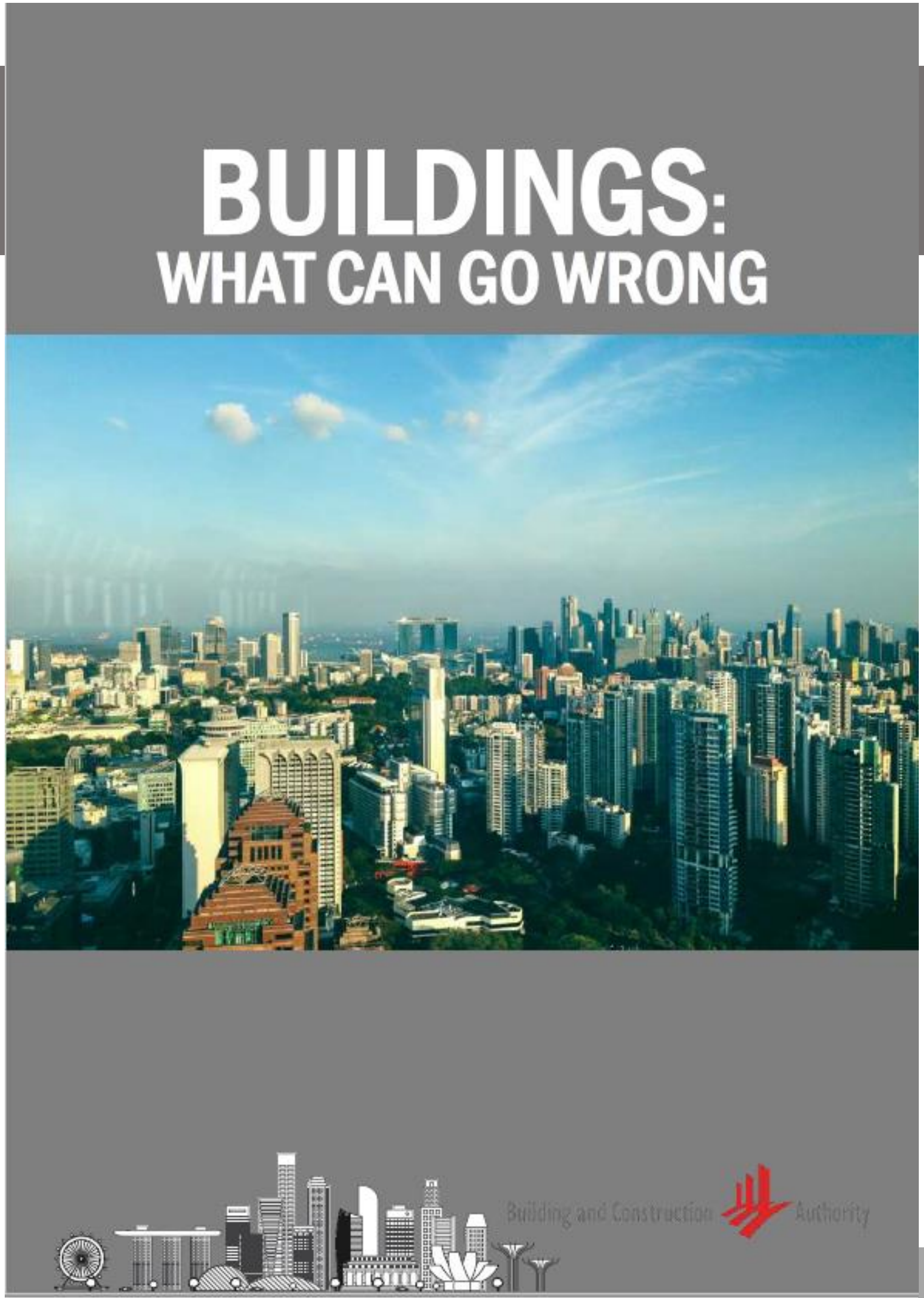
Building and Construction Authority

Overview of Structural Failure

Past failure serves as a reminder for industry practitioners to give due consideration on design and construction with building safety in mind throughout the project life-cycle and beyond.

- Wide array of available digital tools and over-reliance of engineering software have resulted in shorter design period and reduced manpower.

- Increasingly complex structure coupled with advancement in construction technology introduce additional risks and uncertainties in design/construction.



Contents

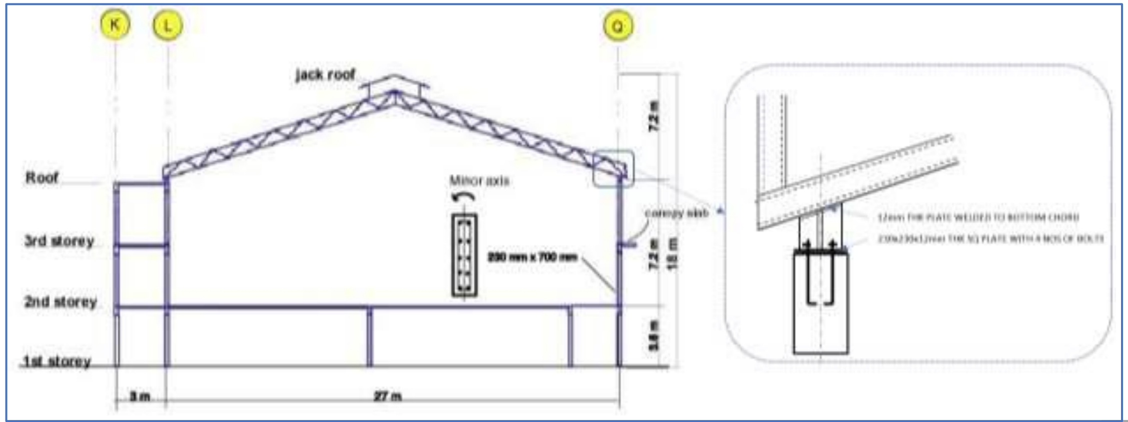
Lesson Learnt

Multi-purpose hall roof collapse

4 storey multi-purpose hall with a pitched roof truss supported by RC column, spanning over 27m. The roof collapsed onto the 2nd storey while under construction.

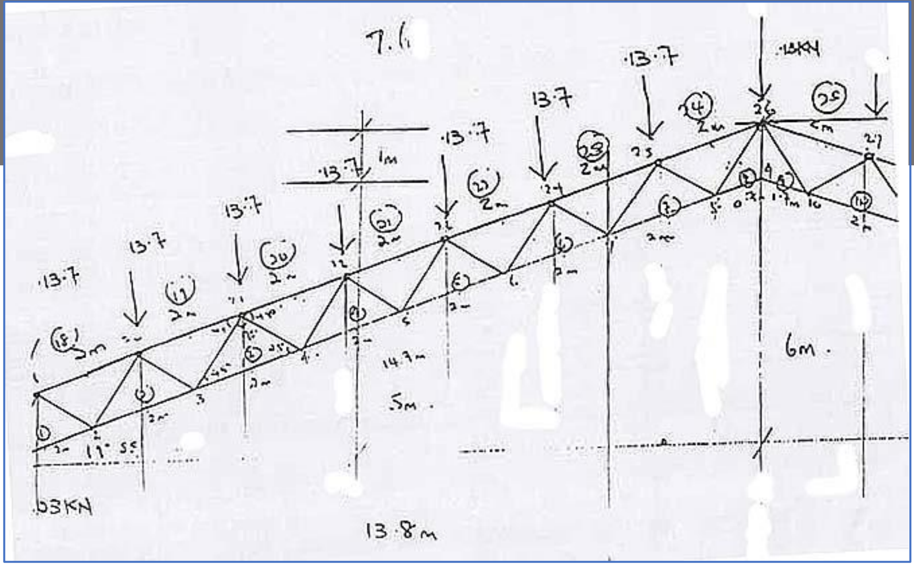
<u>Key triggering factor:</u>

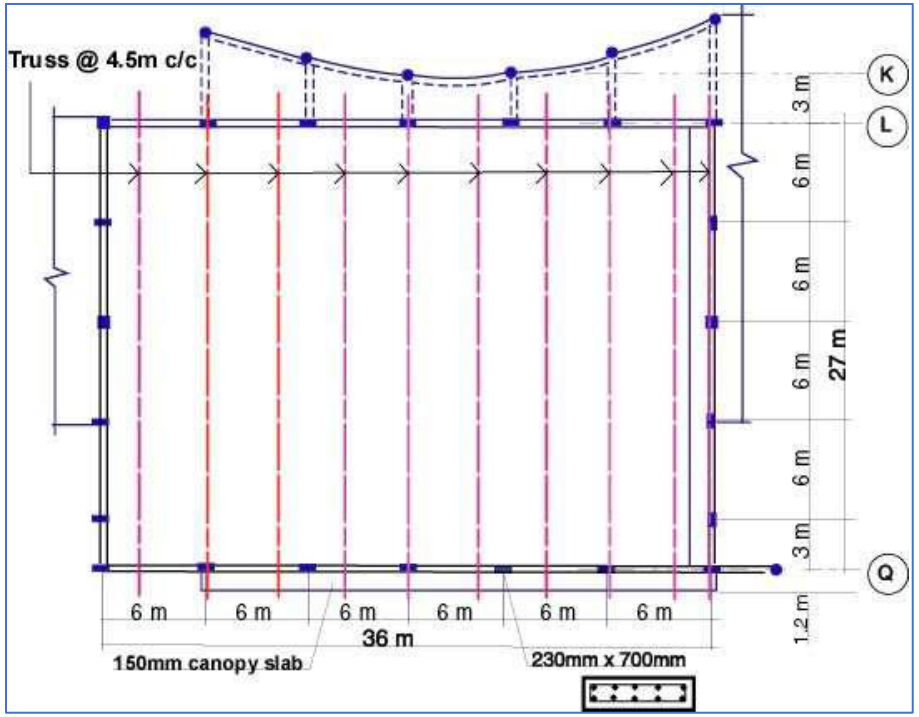
- Inadequate design of the RC column support. Interactions of trusses with the supporting column were not considered.
- The joint support was assumed to be roller-support in the design while fixed bolted connection was provided on site. Outward horizontal forces arising from arching actions of inverted V-shaped truss were transmitted to the column.



Lesson Learnt

Multi-purpose hall roof collapse





- Column was orientated with weaker axes resisting the lateral thrust from the truss. Additional moment due to slenderness were also not considered in the design.

<u>Lesson learnt:</u>

- Interactions of roof trusses with supporting columns and the orientation to resist the lateral thrust should be studied and analysed carefully.
- Connection details to be adequately provided in the drawing to prevent erroneous construction.

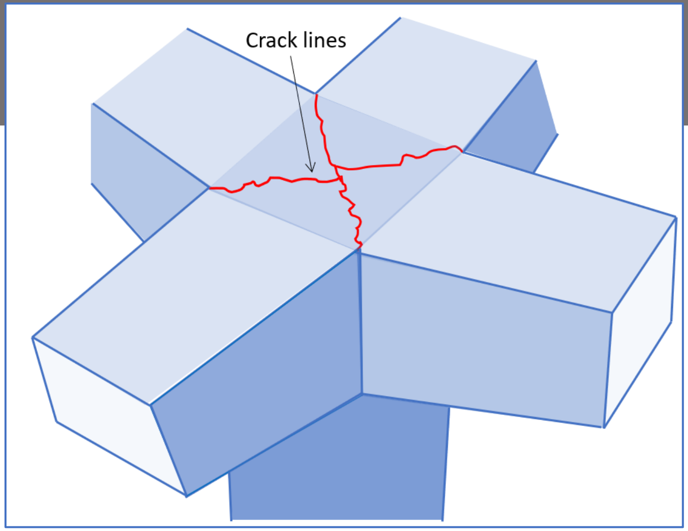
Lesson Learnt

Cracks in tree-shaped column

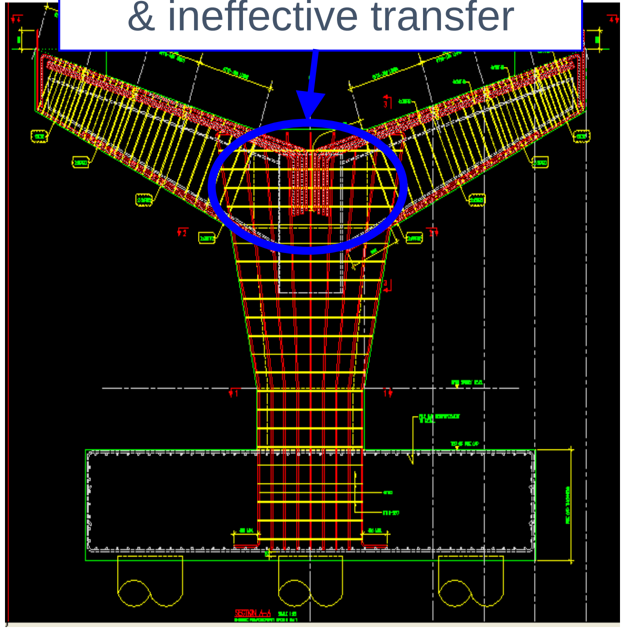
Cracks observed on the column top, side and bearing support of multi-storey building during construction.

<u>Key triggering factor:</u>

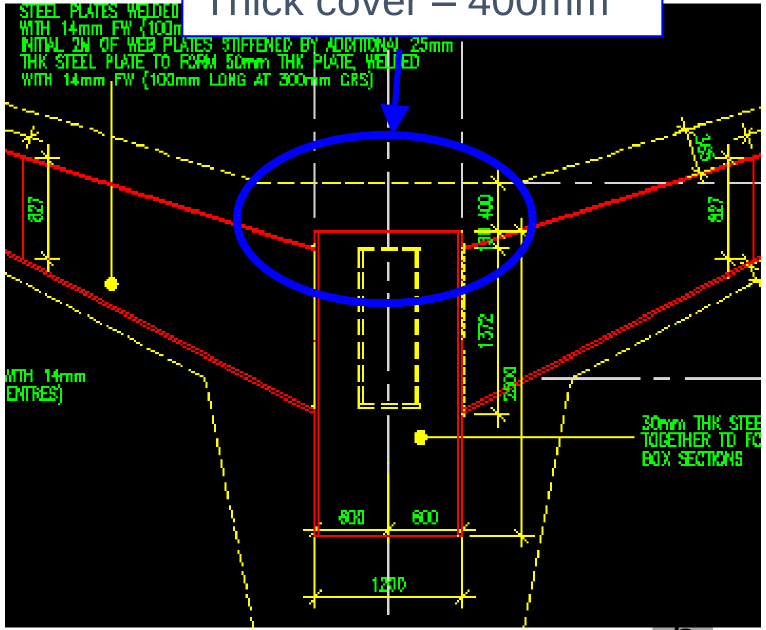
- Thick concrete cover, high stress concentration and ineffective transfer of anchorage force.
- Overlooked detailing issues. Omission of links in the upper part of column that provides restraining force to tie the top of column together so as to prevent the 4 inclined members to act as independent cantilevers.



High stress concentration & ineffective transfer



Thick cover – 400mm



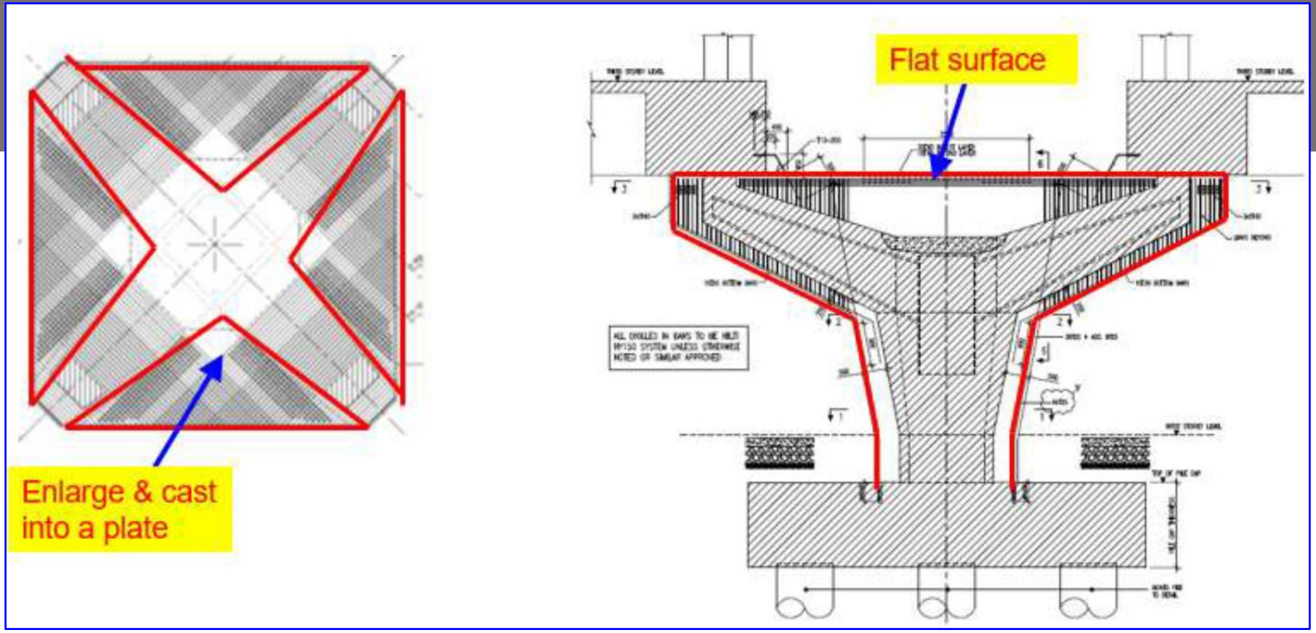
Lesson Learnt

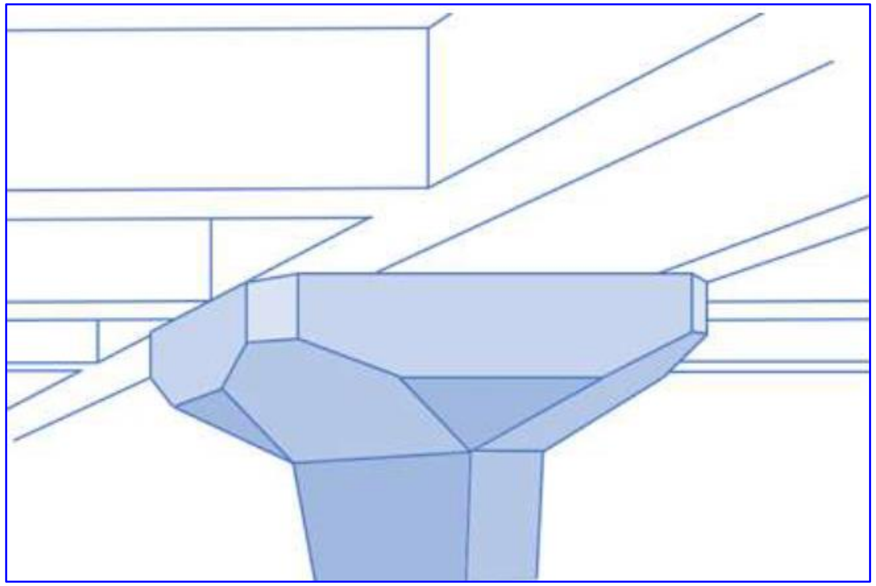
Cracks in tree-shaped column

- Remedial proposal for the column cracks involved casting the 4 inclined members into a single plate and enlarging of the vertical portion of the columns.
- It created a more direct load transfer path in the column to avoid the original path which relied on the provision of the missing links.

<u>Lesson learnt:</u>

- Rebar detailing is critical in areas of high concentration of tension, bending and shear forces.





Lesson Learnt

Post-installed anchor failure

Roof canopy supported by a series of 5m span cantilever trusses collapsed due to joint failure. The cantilever structure broke off from the existing building, debonding the anchors from the supporting RC member.

<u>Key triggering factor:</u>

- Actual anchorage length observed was only half of what it was designed for. The anchors were mostly embedded in plaster.

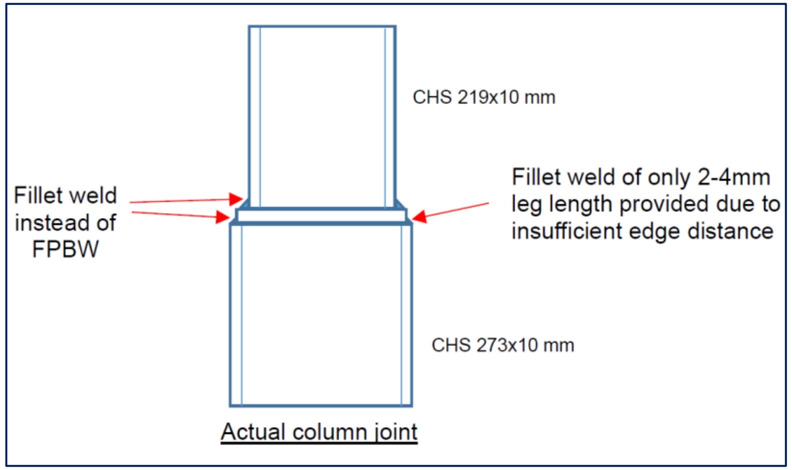
<u>Lesson learnt:</u>

- Inadequate embedment may result in significant reduction in shear and tension capacity of the anchors that eventually led to a failure at the connections.

Lesson Learnt

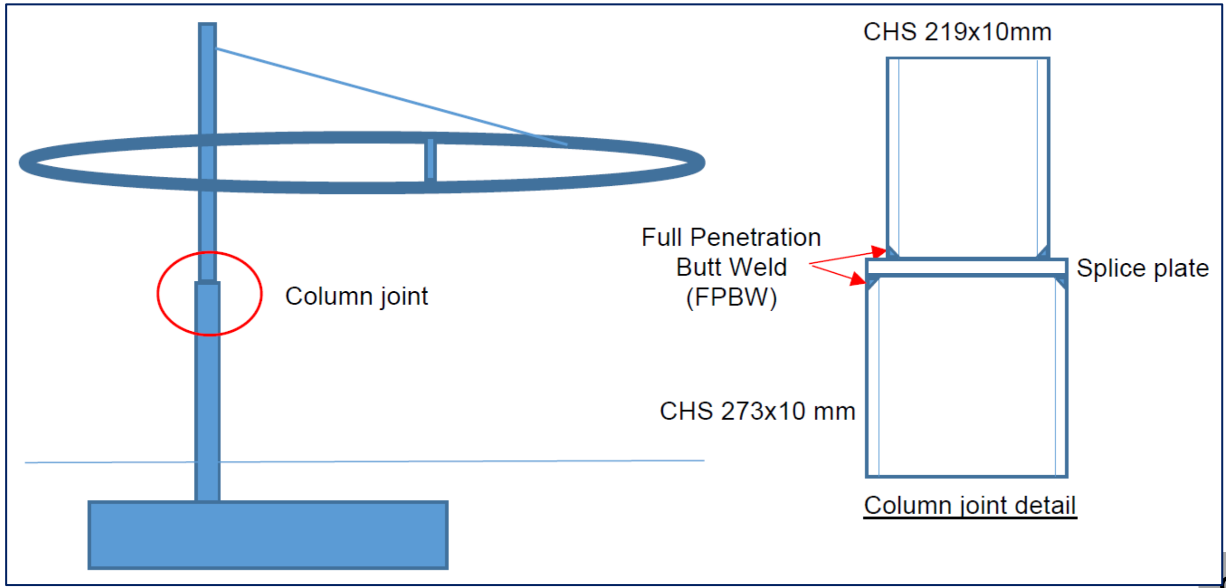
Cantilever member collapse

Cantilever steel canopy serving as a bus bay shelter collapsed at column joint.



Key triggering factor:

- Splice plate was adopted to allow for different column size at lower and upper section. Fillet weld was carried out on site instead of the full penetration butt weld.



Lesson learnt:

- Inadequate joint connection to resist the overturning force in the column may lead to failure.

Lesson Learnt

Cantilever member collapse

6th storey cantilever concrete slab collapsed and triggered progressive collapse of the 2nd to 5th storey corridor slab.

Key triggering factor:

- Inadequate provision of bars observed. Reinforcement 50% less than shown in the drawings.
- Lack of inspection where the rebar rust due to water seepage along the corridor. Sign of corrosion further weakened the cantilevered slab.

FLATTED FACTORY CRASH

Weakened corridor not built according to design

There were not enough steel beams and concrete used was not strong enough, leading to collapse of sixth-floor ledge

By JANE LEE and K.C. VIJAYAN

INVESTIGATIONS into the collapse of five floors of concrete corridors at a Toa Payoh North factory in August have found problems with the construction.

There were not enough reinforced steel bars in the sixth-floor corridor, which later corroded, and the concrete used was not strong enough.

Add to this the weight of 16

anyone was negligent.

Responding to the findings, the developer of the flatted factory at Block 998, Toa Payoh North, JTC Corporation, said: "We are currently consulting our advisers and taking legal advice on the findings in the report."

The 60-page report found that just half the required number of steel bars were holding up the rear corridors, from the second to sixth floors.

They were supposed to be

WHY COLLAPSE HAPPENED

Shoddy construction caused the corridors at a JTC flatted factory in Toa Payoh to collapse, not structural design errors

1. The contractor did not provide enough steel reinforcement bars, placing them 30 cm apart, instead of at the specified 15-cm spacing.
2. Heavy machinery were moved in and out of the factory units and 16 air-conditioning units were hanging below the sixth floor.
3. Cracks formed along the support of the corridor. The left-over surface on the sixth-floor corridor was covered with black oil from a machine workshop there. This shows that the cracks had existed for a long time.
4. Water, and probably chemicals from production units, seeped in and corroded the steel bars, which finally gave way.

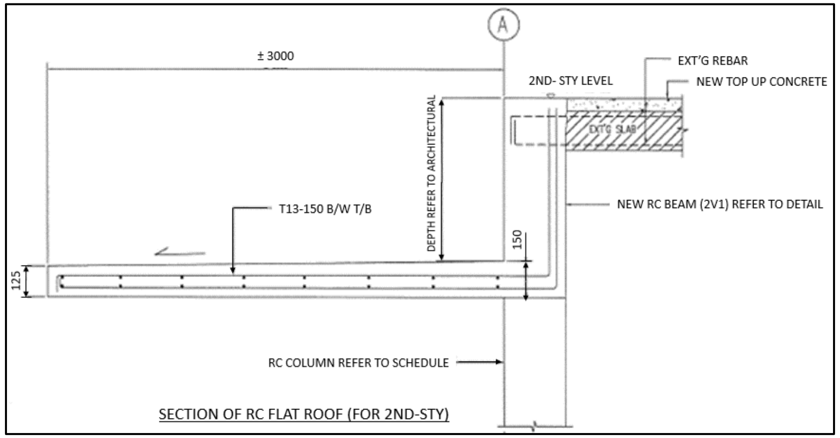
Lesson Learnt

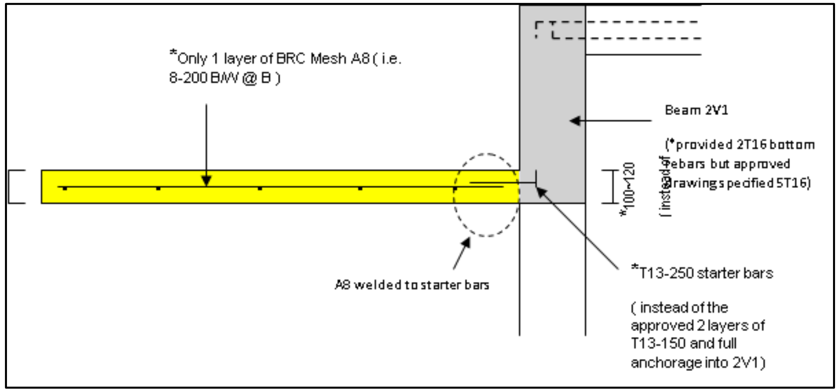
Cantilever member collapse

3m long cantilever car porch canopy slab of a 2 storey semi-detached house collapsed. The canopy slab failed at the joint to the supporting 2nd storey beam.

<u>Key triggering factor:</u>

- Mainly due to insufficient rebar anchorage of canopy slab into the supporting beam, which is critical in providing the necessary tension capacity for the cantilever car porch.
- Instead of full anchorage with rebar bent 90 degrees vertically into the supporting beam, the rebar was found to be horizontally anchored into the supporting beam.





Lesson Learnt

Cantilever member collapse

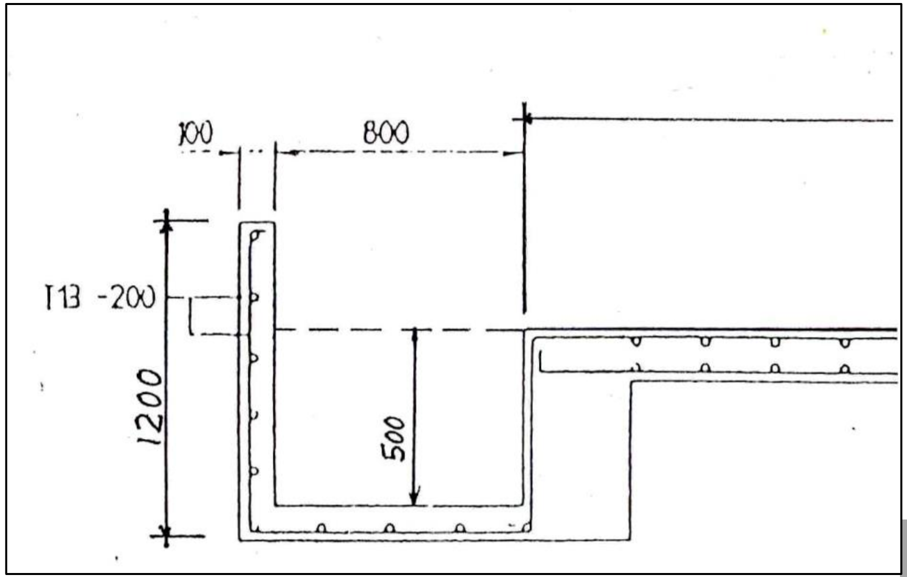
RC gutter detached partially from the roof of 4 storey school after structural work completion.

<u>Key triggering factor:</u>

- Inadequate tension reinforcement for additional imposed load when the gutter was filled with water. No design calculation of the gutter.

<u>Lesson learnt:</u>

- Importance of site supervision and reinforcement detailing, especially in cantilever member where the tension rebar has to be adequately anchored into supporting member to provide the necessary bending moment resistance.



Lesson Learnt

Party wall collapse

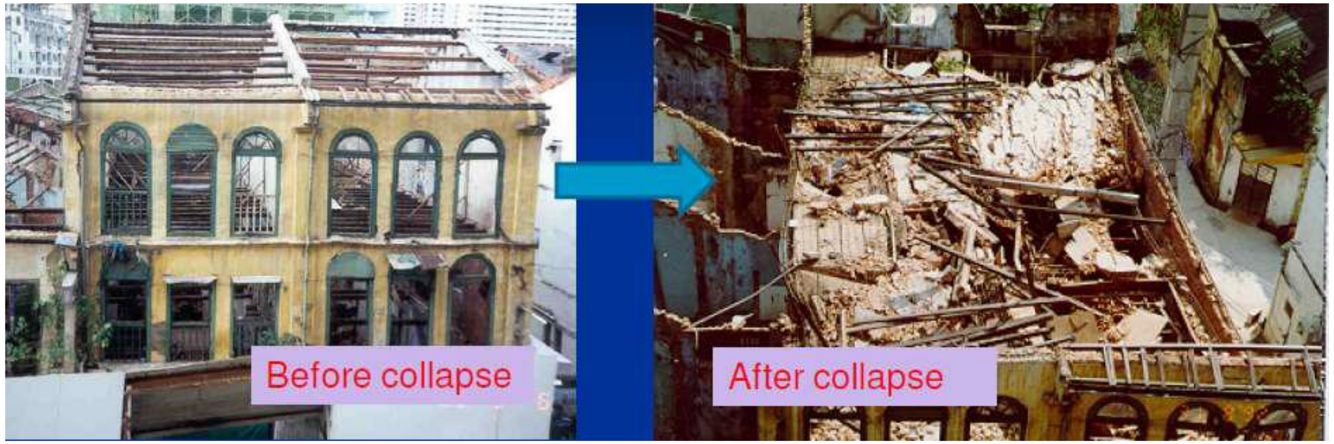
There were a number of incidents involving the collapse of party wall. The shared party wall between houses made of brick was not designed to resist any lateral forces.

<u>Key triggering factor:</u>

- Incidents typically occurred during concreting of the proposed RC wall that abuts the existing party wall. Hydrostatic pressure from wet concrete exerted lateral force on the party wall that may cause collapse.

Party wall collapse

3-storey shophouse collapsed due to hacking of existing party wall to partially embed new columns and beams.



<u>Key triggering factor:</u>

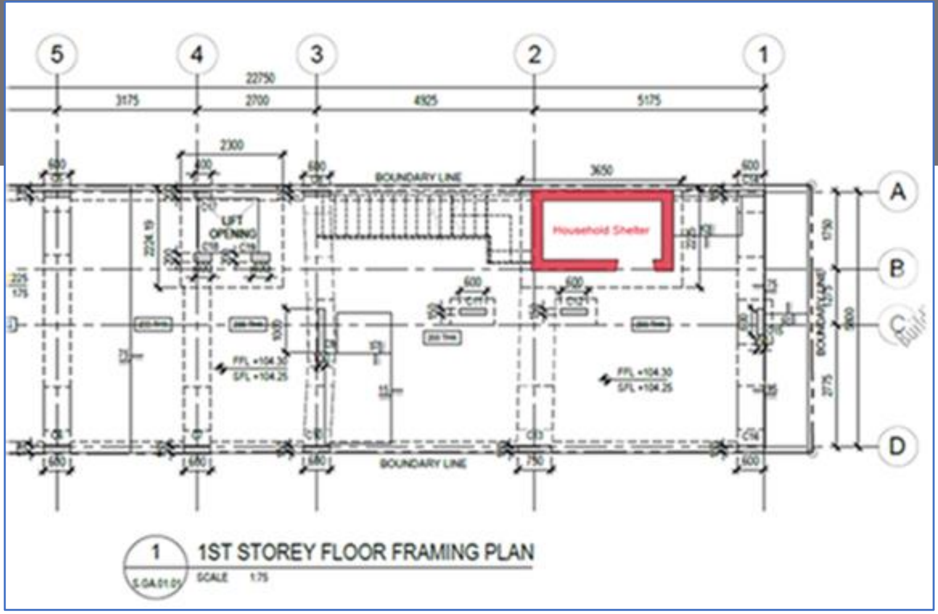
- The common party wall was weakened as a result of chasing of the existing party wall.
- The timber floor joists were also removed without any temporary bracings added, further compromising the overall stability of party wall.

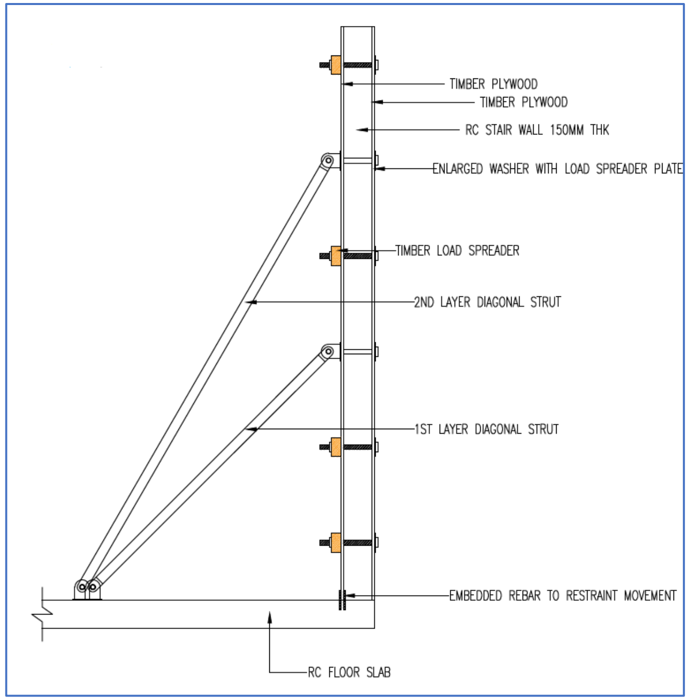
Lesson Learnt

Party wall collapse

<u>Lesson learnt:</u>

- Independent formwork system to be adopted in order not to exert pressure directly onto the non-structural party wall.
- Rate of discharge during concreting is to be controlled.
- Location and condition of existing party wall is to be investigated beforehand to ensure that the wall stability is not undermined during construction.
- No embedment of any structural elements within the existing party wall.





Guides to Improve Safety

Circular on format of structural plan submission

Circular issued on the format of submission for structural plans to provide a systematic listing of the structural elements to be identified for design check in the submission.

Annex B provides a guide on what could be included in design calculations which helps to clearly demonstrate the design of structural elements in a building.

Building and Construction Authority

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ASSOCIATION OF CONSULTING ENGINEERS SINGAPORE

THE INSTITUTION OF ENGINEERS, SINGAPORE

Our ref : APPBCA-2019-07
Date : 05/07/2019

Building Engineering Group (#12-01)
Tel : 1800 342 5222

See Distribution List

Dear Sir/Madam,

JOINT BCA / ACES / IES CIRCULAR 2019

GUIDE ON THE FORMAT OF SUBMISSION FOR STRUCTURAL PLANS

Objective
This circular aims to provide a guide on the format of structural plan submissions for Qualified Persons (QPs) and Accredited Checkers (ACs).

Background
2 Regulation 9 of the Building Control Regulations 2003 sets out the particulars to be shown on detailed structural plans and design calculations. In collaboration with ACES/IES, BCA has developed a guide on the format of structural plan submissions.

Guide on Format of Submission
3 The guide (refer Annexes A1, A2 and B) has been developed based on industry's comments and good practices from plan submissions. The templates in Annexes A1 and A2 provide a systematic listing of the structural elements for QPs and ACs to identify the structural elements designed/checked in their submissions. Annex B provides a guide on what could be included in design calculations which helps to clearly demonstrate the design of structural

...eparation of Annex A1 to list the structural elements designed and ... advised to use the recommended design workflow involving data ...tural analysis and design model and the BIM model as given in Annex ... to allow for a more automated process of listing out the summary of ... be organising briefing sessions to share on the proposed format of ...ended design workflow. More details will be provided via Corenet at

... contents and objective of this circular, ACs continue to have a non-...on 7 of Building Control (AC and ACO) Regulations to review the ...s of building works and perform their original calculations.

...the contents of this letter to your members.

Summary of Structural Elements Sheet
AC should ensure that he has checked all the key structural elements.

S/N	Type of structural elements*	Element markings in structural plan	QP		AC[1]	
			Design Calculations[2]			
			Element markings[3]	Page numbers	Element markings[3]	Page numbers
1	*Footing*	*F1 to F4, F4a, F5 to F7*	*Same as plan*	*5-15*	*Same as plan*	*5 – 18*
2	*Level 1 Beams*	*1B1 to 1B10*	*A-1 to A-10*	*16-30*	*Same as plan*	*19 - 39*
3	*Level 2*	*2B1 to 2B5,*	*A-11 to A-20*	*Refer to*	*Same as*	*40 – 60*

Grouping of Structural Elements Sheet

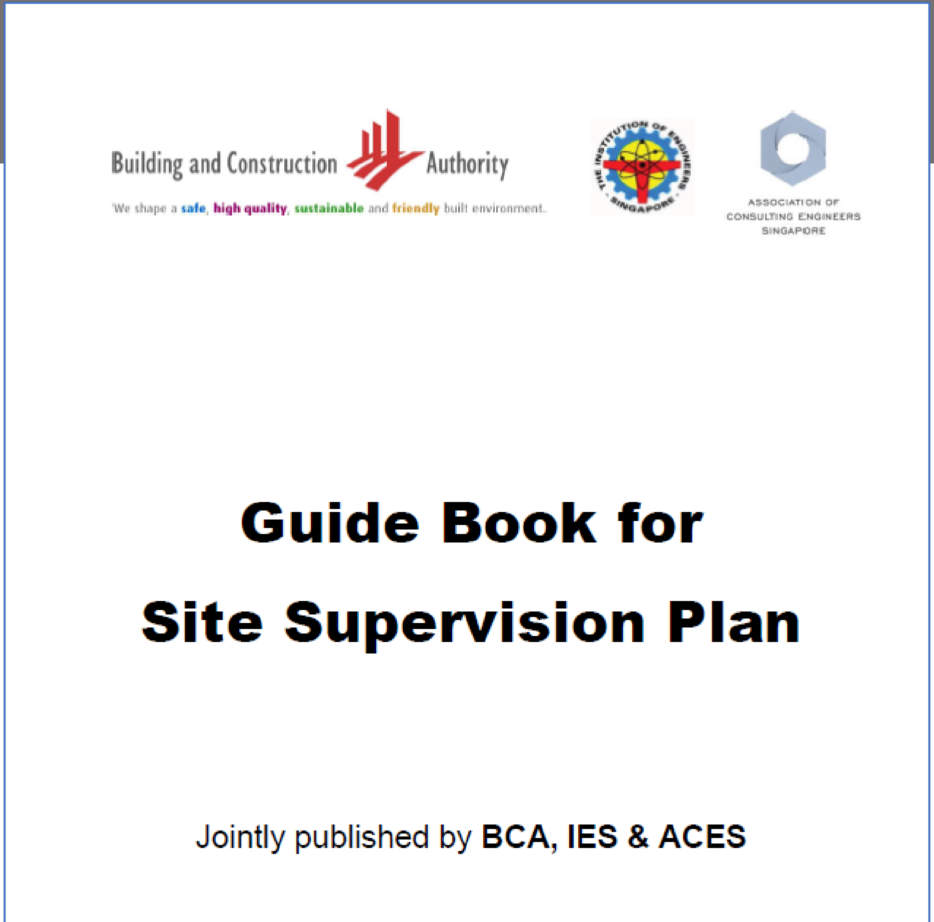
S/N	Type of structural elements*	Element markings in structural plan	Designed structural elements that are similar	Remarks
1	*Beam* *or* *N.A.*	*3B1, 3B2, 3B3, 3B4, 3B5* *or* *N.A.*	*2B1, 2B2, 2B3, 2B4, 2B5* *or* *[to indicate N.A. if there is no grouping in the design]*	*Typical floor*

** All structural elements in the project to be designed/checked, e.g. piles/ earth retaining structures/ retaining walls/ columns/ walls/ beams/ slabs/staircase/barrier.*

Guide for site supervision plan

Guidebook for site supervision plan sets out the principles, requirements and operation of site supervision with risk based inspection regime to take into account the varying risk of different type of works.

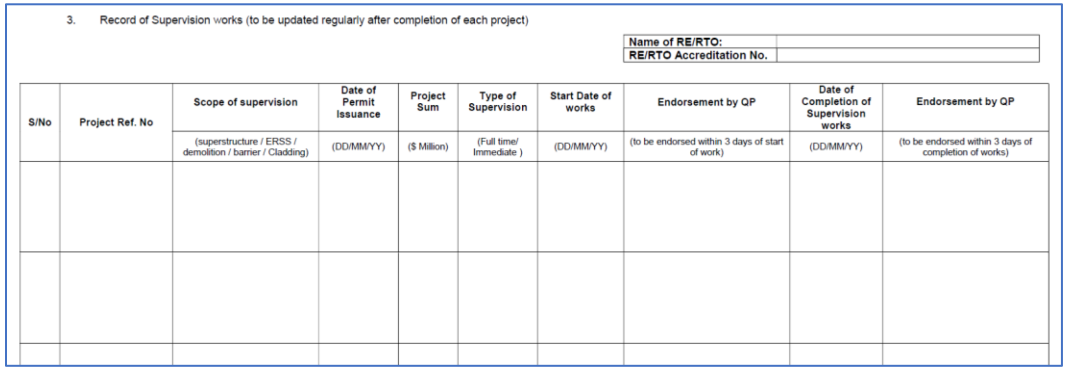
The guide provides comprehensive site supervision plan for small-scale and large building works, with a list of supervision checklist, material test, site record template and recommended good site practices.



Guide Book for

Site Supervision Plan

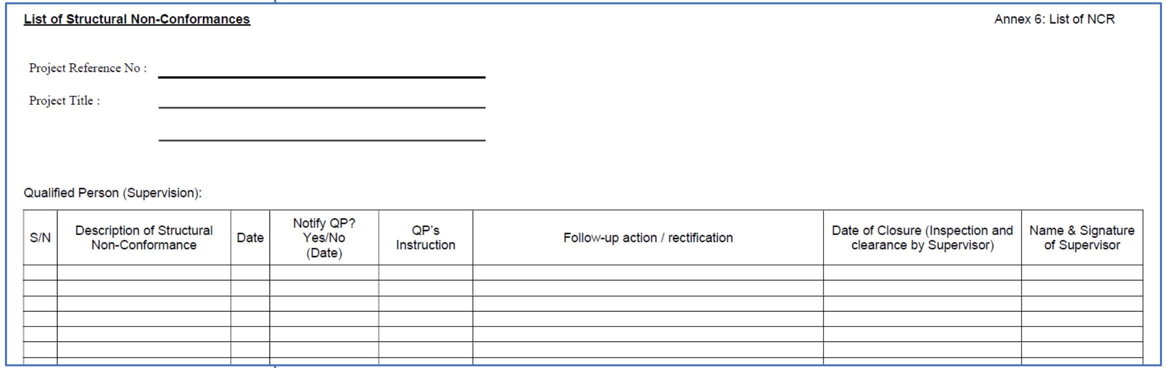
Jointly published by BCA, IES & ACES



3. Record of Supervision works (to be updated regularly after completion of each project)

Name of RE/RTO:	
RE/RTO Accreditation No.	

S/No	Project Ref. No	Scope of supervision	Date of Permit Issuance	Project Sum	Type of Supervision	Start Date of works	Endorsement by QP	Date of Completion of Supervision works	Endorsement by QP
		(superstructure / ERSS / demolition / barrier / Cladding)	(DD/MM/YY)	($ Million)	(Full time/ Immediate)	(DD/MM/YY)	(to be endorsed within 3 days of start of work)	(DD/MM/YY)	(to be endorsed within 3 days of completion of works)



List of Structural Non-Conformances

Annex 6: List of NCR

Project Reference No :

Project Title :

Qualified Person (Supervision):

S/N	Description of Structural Non-Conformance	Date	Notify QP? Yes/No (Date)	QP's Instruction	Follow-up action / rectification	Date of Closure (Inspection and clearance by Supervisor)	Name & Signature of Supervisor

Guides to Improve Safety

Circular on post-installed anchors

Circular issued on post-installed anchors to consider safe selection and installation of post-installed anchors for use in concrete.

Measures to be provided to ensure that the anchors meet the overall design requirement: selection of suitable anchors, corrosion resistance (stainless steel material), preference to adopt cast-in-place anchors over post-installed anchors, sufficient anchorage depth.

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Our Ref : BCA BC 15.0.3
APPBCA-2014-13

Building Engineering Division (#05-00)
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1 Oct 2014

See **Distribution**

Dear Sir/Madam

BS 8539 - STANDARD ON THE USE OF POST-INSTALLED ANCHORS FOR STRUCTURES REQUIRING PLAN APPROVAL

Objective

This circular is to inform the industry on the standard to be complied with when using post-installed anchors for structures requiring plan approval under the Building Control Act.

Background

2 The performance of post-installed anchors is influenced by many factors such as edge distance, spacing, quality and track record of anchors, and particularly, quality of installation. If the anchors are not selected and installed correctly, they might not have the capability to resist the intended loads. Therefore, where possible, cast-in-place anchors should be the preferred option over post-installed anchors.

3 However, if post-installed anchors are to be used, Qualified Persons (QPs) and Builders should follow the recommendations given in **BS 8539 "Code of practice for the selection and installation of post-installed anchors in concrete and masonry"**.

Post-installed anchors for structures requiring plan approval

... selection and installation of ... by providing measures to be ...n requirements.

...es the risk of anchor corrosion ...hors to be of stainless steel ...ons require the anchors to be

of stainless steel material. Furthermore, QPs should be mindful that the required embedment depth for the anchors should be measured from the base material. Any plaster layer should be removed prior to installing the anchors and this requirement should be clearly indicated in the structural plans.

Guides to Improve Safety

Circular on robustness check

Circulars issued on robustness of building to consider the robustness requirements in the design to prevent disproportionate or progressive collapse.

of vertical structural elements, design of key and bridging elements. **We, therefore, would like to remind structural Qualified Persons (QPs) and Accredited Checkers to give due considerations to the robustness requirements in their designs to ensure that buildings are robust and stable so that, in the event of misuse or accident, disproportionate or progressive collapse can be avoided.**

catastrophic as they are likely to result in disproportionate collapse. **Therefore, the use of cantilevered or multiple level transfer structures in buildings should be avoided wherever possible.** A simple structural system with direct load path not only enhances

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Our Ref : BCA BC 15.0.3

Building Engineering Group (#05-00)
Fax : 6325 7482
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02 July 2012

See Distribution List

Dear Sir/Madam

ROBUSTNESS OF BUILDINGS

BCA has observed an increasing number of buildings being built with complex structural layout and systems, such as inclined or curve columns, and cantilevered or multiple levels of transfer structures. Such complex structural layout could have substantial impact on the building robustness and may lead to disproportionate collapse (i.e. collapse of a small area leading to collapse of major parts of the structure). In addition, such complex structures are also more difficult to built and pose higher safety risks during construction. To enhance the robustness of buildings, we would like to highlight some design requirements in the building codes and provide guidelines on the use of transfer structures.

Robustness Requirements

...pelt out in the standards for concrete and steel ...Part 1 (Code of Practice for Structural Use of ...s should be planned and designed so that they ...o effects of accidents. In particular, situations ...rea of a structure or failure of single elements ...tructure. In general, a careful check has to be ...ness in the structural layout for the safe transfer ...ertical ties should be provided to maintain the ... major collapse of building if localised failure ...lude the consideration for the notional removal ... and bridging elements. **We, therefore, would ... (QPs) and Accredited Checkers to give due ...nts in their designs to ensure that buildings are robust and stable so that, in the event of misuse or accident, disproportionate or progressive collapse can be avoided.**

... slab systems have an impact on the robustness ...d or multiple levels of transfer structures would ... the building. Failure of these structures can be ...sproportionate collapse. **Therefore, the use of ...tructures in buildings should be avoided** ...tem with direct load path not only enhances

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Guides to Improve Safety

Circular to ensure structural stability of existing party wall

Circular issued on permit condition to ensure structural stability of existing party/boundary wall when carrying out reconstruction/A&A works.

a) QPs should investigate the location and condition of the existing party wall and boundary wall and adopt suitable design solution to ensure that the stability of the existing walls will not be undermined during construction;

b) QPs should not embed any structural elements within the existing party wall or boundary wall;
c) QP should also avoid placing large and continuous structural elements abutting the existing party wall and boundary wall. If this cannot be avoided, the design should ensure that there will not be any forces (lateral and vertical) being transmitted to the existing walls;
d) During construction, the Builder should not impose any lateral force on the existing party wall and boundary wall;
e) If concreting works are to be carried out abutting existing party wall and boundary wall, the Builder should provide suitable formwork system to ensure that lateral load from the formwork (due to the wet concrete) is not transmitted onto the existing party wall and boundary wall.

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Our ref : APPBCA-2016-01

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1 Feb 2016

See **Distribution**

Dear Sir/Madam

PERMIT TO CARRY OUT STRUCTURAL WORKS – NEW CONDITION TO ENSURE THE STRUCTURAL STABILITY OF EXISTING PARTY WALL AND BOUNDARY WALL

bjective

This circular is to inform the industry of the inclusion of a new condition to the rmit to carry out structural works. The new condition aims to ensure the structural ability of existing party wall and boundary wall when carrying out reconstruction or ditions & alterations works.

ckground

In the past few years, we had observed recurrent incidents involving the llapse of existing party wall and boundary wall during reconstruction or additions & erations works, especially at landed houses. Over the last 3 years, there were a al of 6 such cases (see Annex A for examples of such incidents). There were also idences where existing party walls were indiscriminately hacked to embed uctural elements. Such activities undermine the stability of the existing wall. All se incidents warrant urgent action from Qualified Persons and Builders to ensure structural stability of existing party wall and boundary wall.

easures to be taken

All Qualified Persons and Builders are advised to pay particular attention to sure that the structural stability of any existing wall (either party wall or boundary ll) is not undermined during reconstruction or additions & alterations works. In rticular, the following measures should be taken into consideration when designing d carrying out construction works:

a) QPs should investigate the location and condition of the existing party wall and boundary wall and adopt suitable design solution to ensure that the stability of the existing walls will not be undermined during construction;

Closing Remarks

The building should have simple structural systems with clear and direct load path provision.

- Early engagement in conceptual and design stage with structural driven initiatives.
- Validation of computer outputs and peer review of design by experienced engineer.

The building must be robust so that it can still perform its intended function even if any of its elements were to be removed or failed.

- Provide a robust structural scheme with adequate redundancy.

The building should be designed for any foreseeable risks, including external actions, taking into consideration of ground condition.

- Assess the impact of construction to the safety of nearby buildings.

Thank you

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