Independent Review

Precast Hollowcore Floor Assessment to the MBIE Technical guidelines C5 Wellington Public Library

Contact Details

Name: Carl Ashby

Technical Principal Building Structures

L8, Majestic Centre, 100 Willis St
PO Box 12 003, Wellington 6144
New Zealand

Telephone:
Mobile: +64 27 705 5758

Document Details:

Date: 15-May-2019
Reference: 5-C3862.00
Status: Updated Report

Contents

Document History and Status

Revision	Date	Author	Reviewed by	Approved by	Status
1	12/04/2019	HH	US	CVA	Draft for Client Review
2	29/04/2019	HH	US	CVA	Issued to Client
3	15/05/2019	HH	US	CVA	Updated Report

Revision Details

Revision	Details
2	Aurecon positive moment score amended to agreed value from peer review outcome, minor editorial changes / corrections to body text and header.
3	Reporting format updated, summary tables for July 2017 C5G results amended, editorial changes to body of report for comparison of results.

Executive Summary

In December 2018 following release of the latest "Yellow Book" revision of the MBIE section C5 technical guidelines Wellington City Council (WCC) engaged consulting engineers Aurecon to investigate the seismic risk associated with the precast hollowcore floors within the Central Library Building, and report on the %NBS rating based on the revised C5 Yellow Book document.

WSP Opus have been subsequently engaged by Wellington City Council to review this report and comment on the appropriateness of the Aurecon Report findings with respect to the technical guidelines.

The C5 Yellow Book provides the latest understanding of concrete buildings and precast floor systems. However MBIE has advised that the Yellow Book revisions to Section C5 should not be used for an assessment that a Territorial Authority will use to decide if a building is *Earthquake Prone* and the previous C5 Red Book should be used as this forms part of the current Building Act Legislation for earthquake prone buildings.

The scope of the reporting is limited solely to the comparison of the WSP Opus independent assessment of the rating for the C5E Yellow book against the Aurecon report and results for the Red Book appendix C5G are not included in this report.

The WSP Opus results are provided in the table below and compared to the Aurecon Results.

Table 1. Assessment results MBIE Technical guidelines and the WSP Opus and Aurecon Assessment

	Section C5, November 2018 (Yellow Book)	
	WSP Opus	Aurecon
Loss of Seating	20%	20%
Negative Moment Failure	Not critical	Not critical
Web Splitting	25%	25%
Positive Moment Failure	30%	30% [1]
Torsion	100%	100%

In summary WSP Opus have independently reviewed Aurecon's hollowcore assessment and are in general agreement with the results of their 3D modelling, the assessment methodology, the structural calculations, and the overall finding by Aurecon that the critical structural weakness for the precast hollowcore flooring system is *loss of seating* of the precast floor units in an earthquake.

WSP Opus are in agreement with Aurecon that the Building has an NBS rating of 20%NBS at IL2 based on loss of seating when compared to the latest MBIE 2018 "C5 Yellow Book" technical guidelines.

[1] Aurecon positive moment score amended to agreed value from peer review outcome.

Introduction

In December 2018 following the latest revision of the MBIE guidelines Aurecon were engaged by Wellington City Council (WCC) to investigate the seismic risk associated with the precast hollowcore floors within the Central Library building, and report on the %NBS rating based on the revised document.

WSP Opus have been engaged by Wellington City Council to review this report with respect to the MBIE technical guidelines and comment on the appropriateness of the Aurecon Report findings.

Background

The background to the development of the MBIE guidance on floor assessment is as follows;

In July 2017 the latest revision of *the* ***"The Seismic Assessment of Existing Buildings – Technical Guidelines for Engineering Assessments"*** was issued. This is a document managed jointly by the Ministry of Business, Innovation and Employment, the Earthquake Commission, the New Zealand Society for Earthquake Engineering, the New Zealand Structural Engineering Society and the New Zealand Geotechnical Society.

The part of the technical guidelines covering concrete buildings is Section C5. This section is also known to the industry as the ***"C5 Red Book"*** and the specific section on the assessment of precast floor systems floors is included in the Red Book Section ***Appendix C5G Deformation Capacity of Precast Floor Systems.***

The Red Book Appendix C5G covers various issues with respect to deformation capacity of precast systems and covers in detail the issues observed with hollowcore floors and methodologies for the assessment of diaphragm cracking, elongation, and spalling at the support.

In addition to these requirements the C5 Red Book specifically requires that;

C5G.4.3 Failure of precast floor units

> *"When assessing the capacity of a precast floor unit the following potential failure modes need to be considered:*
>
> - *positive moment failure near support*
> - *negative moment failure near support*
> - *shear failure in negative moment zones*
> - *incompatible displacements between precast floor units and other structural elements, and*
> - *torsional failure of precast floor units*
>
> *Consideration of vertical seismic loading, calculated using Section 8 of NZS 1170.5:2004 should be included…"*

The C5 Red Book further directed the guidelines user that;

> ***"Detailed guidance on how to assess the above failure modes for floors with precast hollowcore units*** *is provided in* ***the University of Canterbury Research Report 2101-02 by Fenwick et al.*** " (and that)
>
> *"Similar principals can be used to assess the performance of other types of floor units."*

In ***November 2018*** an updated revision to the technical guidelines Section C5 was issued. This is known to the industry as the *revised guidelines* or the ***"C5 Yellow Book"*** due to its yellow cover which distinguishes this document from the red book guidelines.

The C5 Yellow Book included substantial updates to the main body of the guidelines for the assessment of the primary structure for concrete buildings and also included updates to several of the appendices, including the precast floor section (now appendix C5E), of the guidelines. The updates to the guidelines included lessons learned from the recent University research and the 2016 Kaikoura Earthquake as well as findings from the MBIE "Statistics House" Investigation.

The new Yellow Book appendix C5E provided an updated version of the previous Red Book hollowcore assessment methodology that was contained within the University of Canterbury Research Report 2101-02 by Fenwick et al. This methodology is now, more conveniently located for users, in the body of the new appendix C5E.

The other revision to the Yellow Book is inclusion of a significantly more detailed methodology for assessment of other types of precast floor systems which were not covered in the same level of detail as hollowcore in the previous Red Book. The new guidelines place particular emphasis on the assessment of failure modes of precast *"double tee"* flooring systems similar to those used in the Statistics House building.

It is understood that, although Yellow Book provides the latest and most up to date understanding of concrete buildings and precast floor systems, the latest Yellow Book revisions to Section C5 should not be used for an assessment that a Territorial Authority will use to decide if a building is earthquake prone and the previous Red book, which forms part of the current Legislation, should be used.

Scope of Review

WSP Opus has been engaged by the Wellington City Council to undertake a review of Aurecon's assessment of the precast hollowcore units in the Wellington Central Library.

The scope of our review has included the following aspects;

- High-level review of the assessment methodology used by Aurecon
- High-level review of the structural modelling, including foundation stiffness and derived drifts
- Review of the interpretation and application of the Section C5 guidelines
- General comments on Aurecon's high-level strengthening scheme

While we agree with Aurecon that;

The use of the November 2018 'Section C5 or Yellow Book, guidelines provide a more refined calculation of the risk which has a been calibrated against observed building behaviour in the 2016 Kaikōura Earthquake and tests from the University of Canterbury and Auckland and are the most appropriate assessment methodology to follow for the seismic assessment of the hollowcore flooring units in the Wellington Central Library.

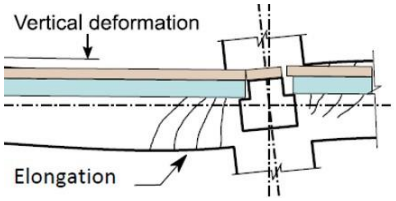
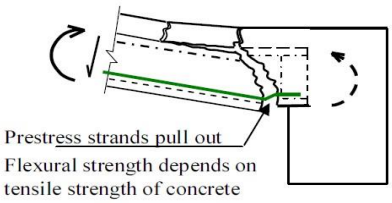
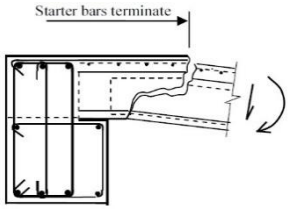
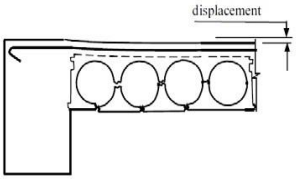
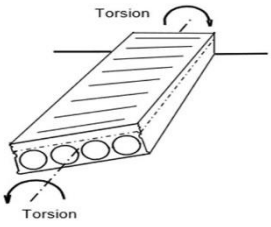
MBIE has advised that the Yellow Book revisions to Section C5 however should not be used for an assessment that a Territorial Authority will use to decide if a building is Earthquake Prone and the previous C5 Red Book should be used as this forms part of the current Building Act Legislation for earthquake prone buildings.

The results for the Red Book appendix C5G, which form part of the Building Act Legislation, are not provided in this report and we have limited this report solely to the comparison of the WSP Opus independent assessment of the rating for the C5 Yellow book against the Aurecon results.

Summary of our Review Results

We have conducted independent calculations on the 200 hollowcore floor units drift capacities as part of the comparative review of the Aurecon assessment using the **Yellow book C5E** guidelines is summarised in the Table format Aurecon used in their report provided below.

Table 2. Comparison of results between the WSP Opus and Aurecon Yellow Book Assessment for Wellington Library 200 Hollowcore floors.

Potential Mechanism	*Yellow Book* %NBS IL2		Failure Mechanism
	WSP Opus	*Aurecon*	
1. Loss of Seating	20	20	
2. Positive Moment Failure	30	*30	
3. Negative Moment Failure	Not Critical	Not Critical	
4. Web-Cracking	25	25	
5. Torsion	100	100	

*Note: Amended value for Aurecon positive moment rating as result of peer review discussions.

Detailed Discussion of Aurecon's results

Sub-Soil Classification - Parameters

Aurecon has assumed that the building is on subsoil Class C in accordance with NZS1170.5 based on interpretation of the GNS subsoil map of Wellington.

We have reviewed the Aurecon assumptions with respect to soil class and based on the available information we agree with Aurecon's interpretation of the GNS subsoil map of Wellington.

Building Importance Level

Aurecon have assessed the building and hollowcore floor rating %NBS based on the building being an IL2 Importance level 2 (or normal) commercial building.

Large buildings, such as the Wellington Public Library, where there is potential for crowds of more than 300 people to congregate in one area are often assessed against the higher design level of IL3 Importance Level 3.

The significance of this is that the current %NBS rating for the hollowcore flooring would be lower than the reported 20% NBS if assessed against this IL3 standard as the building would be assessed against a higher design level earthquake of 1:1000 years return period rather than 1:500 years for IL2 commercial buildings. The purpose of IL3 standard is to recognise the societal importance of public buildings that may contain crowds or high value contents and provide a greater resilience to these buildings than required of normal commercial buildings.

The building has been previously assessed in both by Holmes Consulting Group Ltd in 2013 and by Aurecon in 2016 to the then NZSEE 2006 Guidelines as an Importance Level 2 building based on the building crowd occupancy advised by Wellington City Council that the building will not have congregations of more than 300 people in one area.

We accept that this occupancy level can largely be controlled by management by the asset owner and agree with Aurecon that if this occupancy limitation were to be exceeded the building would likely be re-classified as an Importance Level 3 (IL3) building which would reduce the %NBS scores reported.

Building Drifts and Modelling of Structure

An important parameter when assessing the performance of the hollowcore floor units is to establish an accurate estimate of the imposed displacements that the structure will undergo during a design level earthquake event.

Aurecon have computed the expected deformations based on a 3D Finite Element analysis model of the Central Library building and found the calculated drifts significantly exceed the New Zealand Building Code limit of 2.5%.

Aurecon's 3D modelling gave reported Ultimate Limit State building design drifts of

ΔULS = 3.1% (North-South) Parallel to Victoria St

ΔULS = 3.2% (East -West) Perpendicular to Victoria St

Design Parameters used were: μ=3.0, S_P=0.7, k_{dm} = 1.38, PΔ effects were included via Method B (simplified method)

We have conducted a high level review of the 3D modelling Aurecon has used for the assessment and are in general agreement with the overall results of the modelling.

Our review of the model included a high level review of the sensitivity of modelling parameters which could potentially affect the drift response of the structure, and therefore would ultimately affect the outcome of hollowcore assessment.

We have also checked the variability of building drifts due to rigid zone factor for joint rigidity and combinations of live load for seismic mass and found the derived drift values are not significantly affected by these parameters.

We agree with the Aurecon's assessment of the use of P-Delta effects and the interpretation that the building is largely insensitive to foundation flexibility due to the rigid basement structure.

The drift capacities calculated for loss of seating and positive moment failure are sensitive to the calculated yield drift of the structure. The value used can cause significant variation in the limiting drift and the assessment should consider the yield drifts determined based on the actual frame response.

We have reviewed the information provided by Aurecon for the approximation of the yield drift and based on the information provided we agree Aurecon's assumptions are appropriate.

Our detailed review of Aurecon's hollowcore C5 (E) assessment calculations

Loss of Seating

Loss of Seating of the hollowcore unit is where the support on which the precast floor unit rests is lost due to a combination of factors which include geometric deformations of the building, beam elongation, and spalling of the concrete support itself.

Aurecon have rated this failure mode "loss of seating" as the critical structural weakness for the building with a rating of 20% NBS at IL2.

We have reviewed the Aurecon results and our independent check obtain similar results to that calculated by Aurecon, which gives a drift capacity of 1.2% and a score of 20% NBS (IL2).

Therefore we are in agreement with Aurecon that this failure mode provides the critical rating of the flooring units.

Positive Moment Failure

Positive moment failure can occur in buildings where the hollowcore unit does not sit on a sliding bearing strip and is trapped locally at the ledge support of the end of the unit.

The rotation of the support beam as the building moves in an earthquake can result in the formation of a crack (known as a positive moment crack) on the underside of the hollowcore adjacent the support ledge.

This crack radiates upwards into the unit and when this opens up large enough through beam elongation or rotation a loss of support of the floor can occur.

This failure occurs at a rating of 30% NBS at IL2.

This value amends the original Aurecon rating of 55% NBS which was updated by Aurecon in their assessment report as part of the review process.

This amendment to the positive moment score does not affect the overall %NBS rating of the building as the *loss of seating* is still the critical rating.

Negative Moment Failure

We agree with Aurecon that in general a negative moment failure mechanism is unlikely to limit or govern the rating for the (200mm) hollowcore units within the building.

Our review also looked at several geometric cases and the sensitivity of the parameters used by Aurecon in assessing this failure and we believe the Aurecon assumptions are valid based on the limitations of information available clearly outlined in their report.

It is important to note however this criterion is influenced by the actual construction of the building and there has been limited investigation undertaken to check these parameters.

Our review found there are some instances where the negative moment failure criterion is sensitive to the actual as-built construction of the building and prior to deciding on any retrofit strategy we recommend that detailed (invasive) investigation be undertaken to exclude this failure mode from retrofit.

Web Cracking

We have undertaken independent calculation of this failure criterion and generally agree with Aurecon's results for the web splitting failure.

It is likely web splitting failure will occur for the hollowcore "Alpha Slab" units running parallel and immediately next to beams. Based on the information provided this will occur at a drift of approximately 1.55%, which results in a score of 25% NBS.

Torsion

We have reviewed the information provided by Aurecon in the report and agree that in general torsion demands based on the geometry of the floor are low and is unlikely to be the critical failure mechanism.

Aurecon Concept Strengthening Scheme

The strengthening scheme presented by Aurecon for review is preliminary in nature and could be considered a *high level concept scheme* that addresses the critical issues of loss of seating and web splitting with the hollowcore that were identified by Aurecon in their report.

If a more detailed understanding of the extent of the strengthening works is required by Wellington City Council the concept scheme should be expanded to address positive moment failure and any other potential issues and indicate the level of %NBS rating that is being targeted for the retrofit.

Appendix A

Peer Review Question Log – WSP-Opus / Aurecon

WCC Central Library Hollowcore Assessment - Peer Review

Project: 5-C3862.00

Rev 01 (03-04-2019) Initial Review Queries.	WSP Opus
Response 01 (03-04-2019)	Aurecon
Rev 02 Close-out of queries (10-04-2019)	WSP Opus

Legends:

Closed - subject to close-out action
Ongoing
Item not agreed - Further clarification required
Text in green italics --> Comment only.

ITEM	Reference (drawing number or report section)	Reviewer's QUERY	Remarks / Example	Aurecon response	AGREED CLOSE-OUT ACTION	STATUS
General (03 April 2019)						
1.01	Importance level of the structure	**03/04/2019:** Please clarify the rational of considering the library building as an IL2 structure?		**03/04/2019:** The building was originally designed as an IL2 structure, and was considered as IL2 in the Holmes 2013 DSA. We have provided information to WCC on the impact of the Dycore assessment if considering the structure as an IL3 building. Specific to IL3 we have not considered the building to be one where people generally congregate. Though the floor plate is large and relatively open we do not consider that 300 people will general congregate in one area similar to that of an auditorium. We believe the case for IL3 classification would most likely be based on contents of high value rather than of people present. If WCC decide that they wish to consider the classification as IL3, the %NBS scores can be adjusted for the larger design loads.	Noted. No further comment	closed
1.02	Hollowcore unit dimensions	**03/04/2019:** Please clarify/provide reference for the dimensions used for the hollowcore units for the hollowcore torsion checks, which are sensitive to the dimensions used.		**03/04/2019:** The relevant dimensions for which the assessment is potentially sensitive to relate to the voids. No definitive data was found for the building at the time of the assessment but typical values derived from the guidelines in regards to suggested covers and spacings was used to estimate suggested values for the web and flange dimensions.	Noted. No further comment	closed
1.03	Hollowcore unit strands/prestress	**02/04/2019:** Provided calculations indicate the units contains 11 - 12.6mm strands, whereas standard 200 hollowcore details indicate 7 strands are commonly used. Please clarify/provide reference for the number of strands and level of prestressing used in the provided calculations.		**03/04/2019:** We agree that a value of 7 strands would probably been more appropriate, We have checked our implementation of the relevant calculations. Insofar as negative bending effects are concerned the extra long starters mean that the number of strands are not significant.	Aurecon to update calculation to reflect 7 strands.	closed

1.04	Positive moment failure (PMF)	**03/04/2019:** Please clarify/provide the calculations for the positive moment failure checks. Our spot checks (attached) indicate a capacity lower than your provided outputs for PMF case. **10/04/2019:** Our C5E5.5 interpretation is that rotation of support beam causes the PMF crack to develop, which together with beam elongation, increases in width leading to PMF. It is based on the clause C5E5.5 which states 'Movement of the hollowcore unit, Δ_{tot} , is determined based on beam elongation and support beam rotation as defined in Section C5E.3.) We agree with the limiting value of crackwidth to be taken as per guidelines.	Attachment	**03/04/2019:** Our interpretation of Sections C5E.5.4 and C5E.5.45 is that for trapped units a crack will occur and its width is determined by a rigid body rotation of the support. Further to this the crack has to be limited to the strand diameter and a 12.5 mm diameter may be assumed if no other information is available. This process is not sensitive to the number of strands.	Aurecon to consider clause C5E5.5 and the effects of including beam elongation to the PMF check. WSP opus will provide their supplementary checks on PMF with their report for Aurecon to consider.	closed
1.05	Frame Yield Drift (%)	**02/04/2019:** The yield Drift for frame is estimated in the hollowcore assessment using equations from Paulay & Priestley. Please comment whether any analysis on the frame yield drift conducted to investigate if the estimated value actually refers to the yield drift of frames at first yield? Our spot checks on the frame demands vs yield capacity of beam at level 01 West Frame indicate that Level 01 beams reaches their yield moment at the storey drift of approximately 0.5% instead of 0.97%. The Loss of seating calculation for the units reveals that Limiting Drift reduces from 1.2% to ~0.9%, indicating sensitivity of the hollowcorre assessment on yield drift.	Attachment	**03/04/2019:** We did not use any other means of assessing the potential yield drift. It is our belief that the guidelines provide a method for undertaking the hollowcore assessment process. The original authors may well have considered this type of potential variation when introducing the factor of 2 on the drifts demands.	Noted. No further comments.	closed
1.06	Location of torsion check	**03/04/2019:** Please confirm which frame/section of the structure was considered critical for the hollowcore torsion checks?		**03/04/2019:** The torsion assessment was carried out between grids 11 & 12 where the frames are skewed.	Noted. No further comments.	closed
1.07	300 hollowcore units at ground floor	**03/04/2019:** As the scope of Aurecons assessment on precast floors of WCC Library covers Hollowcore units. Has the scenario of 300 hollowcore at the Ground Floor Level near civic square considered? These 300 HC units are topped with 100mm topping. Along grid 12/grid J and T (central frame of the basement carpark) they are provided with YD24 continuity bars at 150 centres indicating strong starter bars on trapped units (see attachment). Have they been checked for possible failures specially NMF?	Attachment	**03/04/2019:** Not at this stage. It is anticipated that the general checks performed are representative of the critical rating for the building. As part of any further assessment on the building these areas would have to be reviewed more closely.	Noted. No further comments.	closed
1.08	Miscellaneous detailing	**03/04/2019:** Have the implications of additional loading on the hollowcore units been assessed. See attached, details on drawings S3-5, S3-8, and S3-11 show placements of block walls at various locations on the hollowcore units. Detail 10 on drawing S3-11 indicates a detail on hold of a 600 dia RC column supported by a hollowcore unit.	Attachment	**03/04/2019:** Not at this stage. It is anticipated that the general checks performed are representative of the critical rating for the building. As part of any further assessment on the building these areas would have to be reviewed more closely.	Noted. No further comments.	closed

Modelling (03 April 2019)						
1.09	Live load reduction factors	**03/04/2019:** Please clarify the rational of using 0.15 as the combination for Live Loads. The model has used combination factors of 0.3 for the library and 0.15 for other live loads. Assuming this is based on an area reduction factor of 0.5, please confirm if thats applicable for this case of one way slabs? See attached, indicating area reduction factors to be taken as 1.0 for one way slabs.	Attachment	**03/04/2019:** Clause NZS1170.1:3.4.2 relates to the design of the slab units themselves. The use of an area reduction factor for determining the seismic weight of the whole building is recommended practice. Reference can be made to the NCS Red Book on the design of framed structures.	Noted. No further comment	closed
1.10	End length offset	**03/04/2019:** ETABS model indicates a rigid zone factor of 0.5 for both the beams and the columns. Please clarify the basis of using these values. A spot check of the column/beam moment ratio at Level 01 West Frame as per NZSEE guidelines indicates the rigid zone factor should be 1.0 for Column and 0 for Beam. **10/04/2019:** Revised C5 of the guidelines in C5.5.1.7 provides clear guidance on modelling the joint stiffness using Rigid Zone factors.		**03/04/2019:** We used a rigid zone factor that is suggested in ETABS for concrete frames.	Aurecon to consider the sensitivity of the end length offsets by applying appropriate sections of the Revised C5 guidelines which they have used for their assessment.	closed
1.11	Modal Scaling	**03/04/2019:** ETABS model indicates RSA Results are scaled at 100% of the Eq Static loads. Please clarify the rational of scaling up to 100% instead of 80% of Eq. Static Loads. Is the building characterized as irregular as per 1170.5?		**03/04/2019:** We made no attempt to justify the building as regular. Given the presence of the mezzanine floor and the smaler floor plates on levels 4 & 5 it seems extremely unlikely that it could ever be considerd regular under the provisions of NZS 1170.5	Noted. No further comment	closed
1.12	Foundation Springs	**03/04/2019:** Please clarify the basis of Foundation spring values (75 to 400 kN/mm) used in the calculations and model.		**03/04/2019:** The stiffness values were part of Aurecon's previous analysis of the building. These are understood to be based on suggested values from our geotechnical engineers. A comparison of the displacements of the structure based on two extremes stiffness values (75 and 400kn/mm) indicate that the deformations are not sensitive to this pile stiffness parameter. This result is to be expected for a framed structure.	We donot have any information on Aurecon's previous analysis of the building, and therefore take Aurecon's assessment that pile spring values and their basis is appropriate. No further comment	closed

wsp | OPUS

www.wsp-opus.co.nz