Canadian Conference - Pacific Conference on Earthquake Engineering 2023
Vancouver, British Columbia
June 25th – June 30th, 2023

Estimating Seismic Demands on a Subway Station with a 27 Storey TOC Overbuild in Toronto

Janelle Stanzeleit[1], Jose Centeno[2*], Antonio Firmo[3] and Matthew Pearce[4]

[1]Senior Project Engineer, Mott MacDonald, Toronto, ON, Canada
[2]Senior Project Engineer, Mott MacDonald, Vancouver, BC, Canada
[3]Senior Project Engineer, Mott MacDonald, Toronto, ON, Canada
[4]Principal Engineer, Mott MacDonald, Vancouver, BC, Canada
*jose.centeno@mottmac.com (Corresponding Author)

ABSTRACT

The principle of transit-oriented communities (TOC) is to integrate transit, residential, and commercial spaces, enhancing city neighbourhoods and creating more complete places to live, work and play. In some cases, TOC buildings can be placed above or adjacent to a subway station, and constructed after the subway station is built and in operation. A case study is presented of an example 27-storey RC TOC building supported by a subway station. The TOC structural system consists of RC cantilever shear walls, discontinued at the subway roof level with vertical loads transferred by wall-beam elements and lateral forces through the seismic diaphragm. The conceptual design of the transfer elements and an estimate of the design forces are presented. The study also evaluates the use of the two-stage analysis procedure in the design of the subway station, following observations in commentary to NBCC 2015 and provisions in ASCE 7-2016. The resulting demand forces on the supporting underground structure is also evaluated.

Keywords: TOC, reinforced concrete, building code, discontinuous shear walls

INTRODUCTION

Transit Oriented Communities (TOCs) comprise of high density, mixed-use developments. These structures are particular in that they integrate residential, commercial and transit infrastructure through a coordinated design approach. Transit stations have long served to anchor commerce, recreation and retail, and small communities often emerge, centered about such hubs. Given the ever-increasing demand for additional housing within cities, TOCs offer increased density in these areas, providing transit-focused residences in prime locations while enhancing the communities in which they are built.

TOC structures are constructed adjacent to or directly above rail infrastructure (RI). While this is beneficial for the end-user, structurally, additional constraints are often generated through this arrangement. The degrees of interaction between the TOC and RI largely dictate the complexity in the seismic design. While maintaining structural independence between the two structures is sometimes feasible, often, space limits prevent this approach, and station and overbuilds are integrated. In these cases, a critical aspect in implementing future TOC structures is the deliberate overdesign of station infrastructure to resist loads well beyond that required for their single storey construction. To fulfill this obligation, forethought must be invested to establish such loads, pre-determine allowable connection methods, and predict proximity implications between the two inter-dependent structures.

In the case of several TOC structures anticipated to be developed over the next 10 years alongside the delivery of new rapid transit in Toronto, such interface defining documents are developed. These aimed to provide projected demands from the future TOC structure on the station infrastructure. The following paper discusses the method employed to determine and report the overbuild structure loads and protect the station infrastructure for the construction of the TOC.

DESCRIPTION OF THE TOC CASE STUDY STRUCTURE

To adequately design the station infrastructure, sufficient information must be provided to allow the design to be fulfilled, accommodating strength, serviceability and ductility requirements imposed by the future addition of a high-rise structure above. Recognizing that the design and construction of the station are likely to take place before the overbuild developer is selected, a concept TOC design must be developed upon which the TOC loads can be based.

Coordination between station and TOC advisory teams produce integrated reference designs. Wall and column locations and profiles are carefully positioned through the station footprints, and station clearances are protected to accommodate large transfer elements. It should be noted that, project concept designs are developed to 10%-30% of the final design while the TOC structural design is advanced to nearer 60% to allow sufficient detail in the reported design loads. Further, flexibility must be designed into both the station and the TOC designs as neither concept is prescriptive, and thus each is largely changeable.

Supporting Rail Infrastructure

The rail infrastructure references the combined overbuild, station headhouse and station substructure elements, which make up the transit station at the case study site. This structure is illustrated in Figure 1.

The station headhouse will be a double height single storey structure. The roof diaphragm, in combination with concrete transfer beams are designed to transfer loads from the overbuild columns and shear walls to the station structure elements. The Seismic Force Resisting System (SFRS), in both orthogonal directions, consist of a reinforced concrete shear wall system.

The station underground structure is anticipated to be a bored tunnel accessed via vertical shaft centered below the station entrance building. The shaft extends approximately 40 m below street level and ties into the tunnel through a 13.7m wide adit. The access shaft is expected to be founded on a cast-in-place mat foundation resisting uplift though a rock anchoring system.

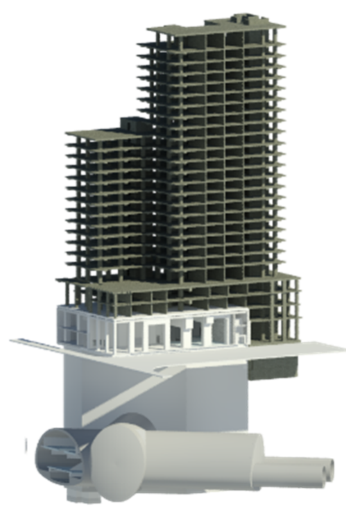


Figure 1: Rendering of the Concept Rail Infrastructure and TOC Overbuild

Description of the TOC Overbuild

The case study TOC structure is developed as a residential building. As is common practice for high-rise residential buildings in Toronto, the structure is designed to be constructed of cast-in-place reinforced concrete. The structure is comprised of a 5-storey podium with a 27 storey tower, made up of two interconnected rectangular footprints, as shown in Figure 1. At levels 01 and 02, the residential building fills the unoccupied area of the site boundary, abutting the south face of the station headhouse. Levels 03 to 05 extend over and above the station entrance roof, utilizing the length of the site. The footprint is then set back to form the tower, with amenity spaces and green roof occupying the exterior Level 05 roof area. The shorter portion of the tower extends to a height of 58m above street level while the taller section reaches a full height of 89m.

Seismic Force Resisting System Layout

The shear walls in the structure are positioned as illustrated in Figure 2. Where feasible, the walls were kept continuous between the station and TOC overbuild structures. However, the location of the SFRS elements within the station were limited by the operational and aesthetic constraints of this infrastructure.

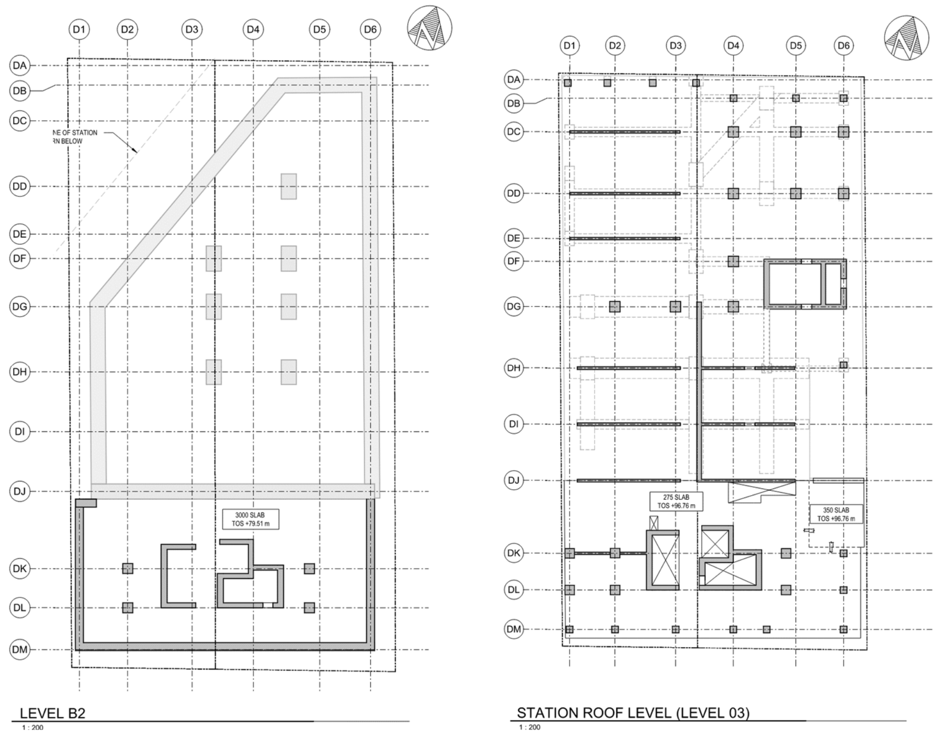


Figure 2. Structural shear wall layout at level B2 and station roof level

The walls have been divided into categories for the purposes of reporting the results of this study. The categories are listed below.

1. Discontinuous walls: Beginning at the station roof, the TOC uses east-west shear walls which frame the residences and rise through the tower to form the primary gravity support system. In the north-south, a fully coupled shear wall frames the corridor. These walls are located on gridlines DI, DH, DE, DD and DC and east of gridline D3.
2. Stairs (TOC and Station): A stair core through the overbuild structure is retained in the station, acting to partition the space in the back of house area of the headhouse. These walls are located between gridlines DF and DG.
3. Wall Gridline DJ: A thick shear wall forms the station exterior south wall. In the overbuild, it is divided into two to allow for the corridor. This wall is continuous from the top level of the overbuild down through the station entrance shaft.
4. Elevator Walls: Within the TOC area adjacent to the station, a concentration of elevator cores and stairwells provide a set continuous shear walls over the full height of the TOC, terminating within this structure's basement. Theis category includes all the walls south of gridline DJ.

SEISMIC DESIGN PARAMETERS

The TOC building is expected to be designed and constructed after the year 2025. As such, it is anticipated that it will be designed in accordance with provisions in OBC 2024 [1] which align with the current NBCC 2020 provisions [2]. Design of the TOC overbuild to NBCC 2020 is presented in an accompanying paper [3].

To maintain a consistent design approach, the station was equally designed in accordance with NBCC 2020 in this study. Accordingly, the station's importance factor and seismic category designation are determined in accordance with NBCC 2020 Tables 4.18.5A and 4.18.5B, respectively. A normal importance factor was assigned to the structure and as such I_E is equal to 1.0. Geotechnical studies at the site classified the ground conditions as Site Class C and reported the average shear wave velocity, V_{S30}, to be 477 m/s.

Design Spectrum and Seismic Category

The design spectrum is determined based on the site's location and measured, V_{S30}, using the seismic hazard calculator for NBCC 2020 [4]. The resulting spectral accelerations, $S_a(T, X_{V=477m/s})$ are illustrated in Figure 3.

The station headhouse is assigned a seismic category SC3. This category is assigned because the design parameter, $I_E S_a(0.2)$, is equal to 0.356 which is within the specified range of 0.35 to 0.75 [2].

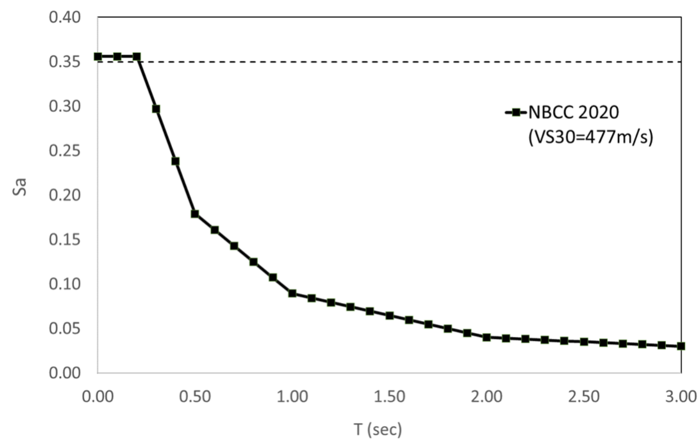


Figure 3: Design spectrum for station headhouse based on NBCC 2020

TOC-STATION DESIGN INTERFACES

In the case of the 27 storey TOC overbuild discussed in this study, the TOC and station structures are fully integrated. This increases the level of complexity in the design. Understanding the fluid nature of the two inter-dependent designs, specific design elements and interfaces are identified as common, and these are fully or partially specified in the design. That is, aspects of the design are fixed, to allow each designer to progress their scheme independently while ensuring key design parameters are known and can be relied on.

Seismic Force Resisting System

Integration of the station infrastructure and the overbuild results in the interconnection of their lateral systems. To maximize flexibility for the future TOC, the lateral system within the station superstructure would favorably use a low RdRo value to limit inelastic deformations. Thus, conventionally constructed shear walls are prescribed. It is considered that this will induce the largest earthquake forces for its design and will avoid imposing added ductility requirements to the TOC above.

Given the SC3 seismic category, the TOC overbuild falls outside the allowable height limit to design the structure with conventionally constructed shear walls [2]. Consequently, The TOC overbuilds' SFRS is required to utilize, at minimum, moderately ductile concrete construction. This introduces a vertical variation in $R_d R_o$ over the height of the structure.

This approach, which forces differing lateral systems, is taken intentionally. It creates a scenario where the inelastic behavior will be confined within the moderately ductile SFRS and attempts to limit the lateral forces transferred to the station headhouse. The structural design aims for the plastic hinge region to develop at the base of the TOC overbuild and away from the station headhouse.

Physical Interfaces

Connection points on the station infrastructure are required to fully integrate the station and the future overbuild. The coupling points are dedicated locations and are the only locations where TOC elements are permitted to connect to the station. No post-installed anchoring will be permitted.

The station roof is an important horizontal interface between the overbuild and the rail infrastructure. The station roof forms level 03 of the overbuild structure and supports the TOC walls and columns which initiate the framing system for the TOC. Concrete plinths will be provided over this surface to adequately couple the vertical elements with the diaphragm. This is critical as the roof equally acts to transfer lateral loads from the discontinuous TOC shear walls to the station SFRS below. The roof is equally required to act as a construction platform, allowing the TOC construction to take place while the station remains operational. As a result of the TOC dependance on this element, the elevation of the roof is specified in the station design.

The south exterior station wall equally provides direct support for the TOC elements. Structural slabs frame into this wall from the basement level up to level 03. In addition, four basement walls tie into the station shaft wall, utilizing the station foundation wall to form a length of the TOC basement's perimeter. Finally, the continuous nature of the wall between the TOC and the station, create a continuous lateral load path from level 27 to the station foundation.

Minor dimensional tolerances are allowed for each connected element. These vary based on the element and generally allow for minor design modification, construction tolerance or account for uncertainties at the site. The station designer may utilize the provided tolerance; the future overbuild developer will be restricted by the locations set by the station designer. However, at all locations where connection loads are provided, the station designer is required to provide supports. That is, if the station extents are reduced, supports must still be provided where such locations are defined.

Capacity Design

The number of discontinuous walls in the TOC adds various considerations into the seismic design, as per NBCC provisions. Notably, this includes:

1. The design of the SFRS supporting elements for the lateral load capacity of the SFRS (NBCC cl 4.1.8.10.5), and;
2. The prevention of a weak storey mechanism (as per NBCC cl 4.1.8.10.1).

Analysis and design to meet these criteria are required in the TOC reference concept design. As seismic provisions often reference the "lateral load capacity of the SFRS" in capacity protection applications, the TOC SFRS elements form the basis of design for all those which exist in the stories below. Here it should be highlighted that, due to the sequence of design, the lateral capacity of these elements may be unknown at the time of the station design. This requires that minimum storey shears be reported to the station design team to allow for an informed design. The analysis approach and design results associated with the implementation of these seismic provisions are presented in the accompanying paper [3].

Building Movements

The construction of the TOC on the station headhouse will evidently result in deflections through the station. These, in turn, have the potential to highly impact the serviceability of the overbuild, causing widespread cracking over the height of the structure. Applying a phased approach in evaluating loads would be required to ensure allowable movement limits over the lifespan of the structures. Where the overbuild is directly connected to the station, the station deflections, after the connection of the TOC, are limited as detailed in Table 1.

Table 1. Deflection Limits at Station Headhouse

Location	Loads	Deflection Limit	Deflection Type
Street Level	Gravity + Earth	5 mm	Horizontal
Street Level	Earth + Wind	5 mm	Horizontal
Roof Level	Gravity + Wind	H/500	Horizontal
Roof Level	1/2475 Year Seismic	H/40	Horizontal
Roof Level	1/475 Year Seismic	H/250	Horizontal
TOC supports	TOC Loads	L/500[1]	Angular Distortion
Any	All	20 mm	Vertical

1. L in this instance represents the distance between the TOC overbuild structural supports

ANALYTICAL MODEL

The structural analysis is conducted using the commercial software ETABS [5]. Shear wall elements and transfer beams are modeled using shell elements, supporting columns and coupling beams using frame elements.

Shear walls and coupling beams are assigned stiffness modifiers in accordance with CSA A23.3:19 Table 21.1[6]. Stiffness modifiers for shear walls, α_w, are set equal to 0.9 based on the SFRS's R_dR_o value of 2.8 and the lower estimate of the SFRS overstrength, γ_w, equal to 2.15[1].

Station columns supporting discontinuous walls are assigned moment releases at top and bottom ends. This approach is taken to ensure lateral forces from discontinuous walls are not taken by the supporting columns but instead transferred through diaphragm action to adjacent shear walls.

Floor slabs are modeled using shell elements with semi-rigid diaphragm constraints. For the sensitivity study, all diaphragm's in-plane axial and shear stiffness properties are assigned modifier values as shown in Table 2, following recommendations in the commentary of CSA A23.3-2014[7].

Structural Models

Three structure models are used throughout this study. Model 1 includes the entire structure: TOC overbuild, station headhouse and station substructure. Model 2 consists of the TOC overbuild including the TOC area adjacent to the station. Model 3 includes the station headhouse and substructure, combined with the TOC adjacent area up to the station roof. All three structural models are illustrated in Figure 4.

The models, and their associated results, assign the x-axis to the east-west direction and the y-axis to the north-south direction.

Table 2. Diaphragm In-plan stiffness modifiers

	In-plane axial stiffness	**In-plane shear stiffness**
Upper bound	0.50	0.50
Benchmark	0.25	0.25
Lower bound	0.10	0.10

Linear Dynamic Analysis

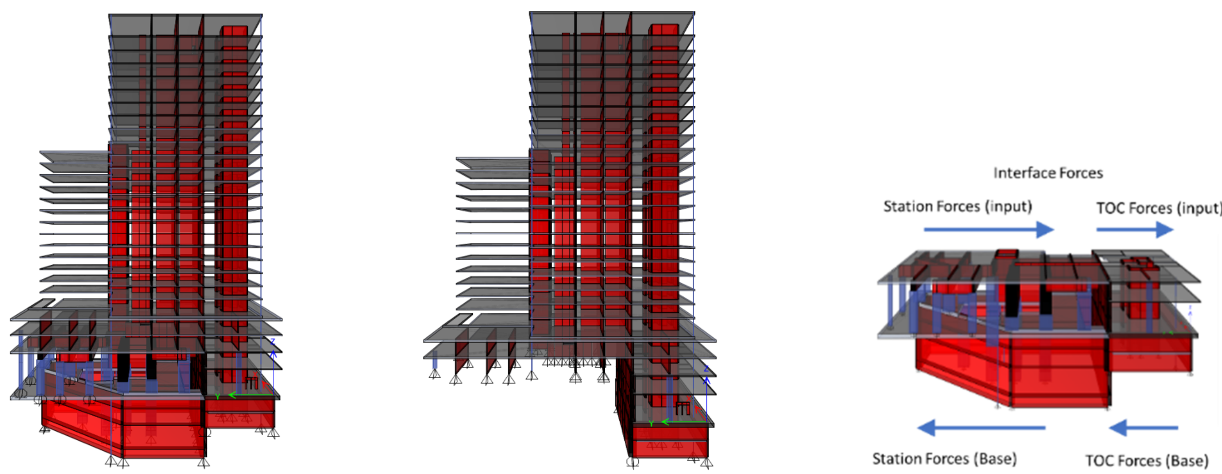
The analysis uses the response spectrum analysis (RSA) method applying the site's design spectrum for a damping ratio, ξ, of 5%. The analysis is performed in accordance with NBCC 2020 clause 4.1.8.12. Modal analysis is checked to have a minimum 90% mass participation for both directions. The resulting base shear is scaled to 100% of the specified lateral earthquake force, V, calculated in accordance with NBCC 2020 clause 4.1.8.11.2.

Seismic loads are also enveloped to consider accidental torsion. In each direction, three cases are enveloped to report the most severe force. For example, in the x-direction, the force is reported as an envelope of the below loads cases:

- Earthquake load in the X
- Earthquake load in the X, with 10% eccentricity in Y+
  Earthquake load in the X, with 10% eccentricity in Y-

SEISMIC DEMANDS AT DESIGN INTERFACE

The TOC overbuild seismic loads at the station roof are determined using results from response spectrum analyses. The magnitude of these loads depends on the support conditions at the base of the TOC overbuild and backstay effects developed due to the additional shear walls in the station headhouse.



(a) *(b)* *(c)*

Figure 4: Models in sensitivity study (a) Model 1: Entire structure, (b) Model 2: TOC Overbuild, (c) Model 3: Station with adjacent TOC

The authors determine the interface forces by following a sensitivity study, consisting of four analysis cases. Cases 1, 2 and 3, correspond to upper bound, benchmark, and lower bound conditions, respectively. Each case uses the corresponding stiffness modifier specified in Table 2. These analyses are all run using Model 1. Case 4 corresponds to a fixed boundary condition for the TOC overbuild, representing greater lateral stiffness in the station's SFRS. This analysis is run using Model 2.

Results of the sensitivity study are presented in Table 3 and Table 4, corresponding to earthquake loading in X and Y directions, respectively. Values presented are taken directly from the response spectrum analysis and are not amplified by any values of overstrength.

Discontinuous walls supported at the interface develop greater seismic demands for the fixed support condition, and lowest demands for the lower bound case. The walls in the stair core, continuous through the TOC and station, show the governing condition to occur for the upper bound case for the X direction, and fixed condition, for the Y direction. In contrast, continuous walls, such as elevator walls and the wall along GL-DJ, show greater forces develop for the benchmark and lower bound cases.

The design interface loads reported are taken from the envelope of all four cases in the sensitivity study. An added contingency factor equal to 1.20 is applied to all results, excluding the fixed support condition case. This factor allows for small variations made to TOC during development.

In addition to the forces from the RSA, the interface and station must be capacity designed [3]. Therefore, the value of the SFRS's lateral capacity is also submitted to the designer, as part of the interface force data.

Table 3. Sensitivity Study Results – Seismic Loads X-direction.

Seismic Diaphragm Stiffness	Discontinuous Walls (TOC) (kN)	Stairs (TOC & Station) (kN)	Wall GL-DJ (TOC) (kN)	Elevator Walls (TOC) (kN)	Storey Shear Level 3 (kN)
Case 1: Upper bound	5278	2904	5278	1530	9890
Case 2: Benchmark	4088	2048	5611	1568	8914
Case 3: Lower bound	2865	1135	5246	1548	7787
Case 4: Fixed support condition	6273	1728	2759	875	10346
Envelope	6273	2904	5611	1568	10346
Reported value	6273	3485	6733	1882	N/A

Table 4. Sensitivity Study Results – Seismic Loads Y-direction.

Seismic Diaphragm Stiffness	Discontinuous Walls (TOC) (kN)	Stairs (TOC & Station) (kN)	Elevator Walls (TOC) (kN)	Storey Shear Level 3 (kN)
Case 1: Upper bound	7259	1800	1427	9239
Case 2: Benchmark	5908	1963	1528	8600
Case 3: Lower bound	4308	1945	1821	7576
Case 4: Fixed support condition	7802	4141	1750	10827
Envelope	7802	4141	1821	10827
Reported value	7802	4141	2185	N/A

MODIFIED TWO STAGE ANALYSIS

NBCC 2020 is limited in recommendations for analyzing a structure that will be constructed in two stages, which ideally could be modeled implementing a two stage analysis procedure. Seismic provisions in ASCE 7-16 present a prescribed approach of this procedure, where the structures, above and below, can be analyzed as separate structures [8]. Similarly, in the commentary to NBCC 2015 clause 4.1.8.9.(4) [9], a two stage analysis is suggested to analyze structures with vertical variation in ductility values, R_dR_o.

Standard two stage analyses can only be implemented when the structure below has sufficient lateral stiffness as not to develop a dynamic structural interaction with the structure above [8,9]. In the commentary to NBCC 2015 clause 4.1.8.9.(4), the lateral stiffness requirement is set equal to 3 times greater than the storey stiffness above. In ASCE 7-16, lower structure's stiffness requirement is set at 10 times the upper. Given the properties of the station and TOC, the standard two stage analyses cannot be used for this case study.

This study proposes a modified two stage analysis in order to capture the dynamic interaction between the TOC overbuild and station. The modification consists of modeling the station as a separate structure, while the TOC overbuild is analyzed using a model of the entire structure. As a result, the interface forces are developed from the TOC overbuild and include the effects of the interaction between the two structures.

To evaluate the modified two stage analysis, this study follows the suggested approaches in the commentary to NBCC 2015 clause 4.1.8.9.(4) [9]. Option 1 determines forces using the entire structure, while option 2 is the modified two-stage analysis approach, using model 1 for the entire structure and model 3 for the station. Both options are compared for a) forces obtained from linear dynamic analysis and b) forces related to the lateral capacity of the TOC overbuild. The four analysis cases are further explained below:

- Option 1a: RSA analysis using the station's R_dR_o value of 1.95 and using Model 1.
- Option 2a: Interface forces reported in Tables 3 and 4 combined with station's RSA results, using the station's R_dR_o value of 1.95. Analysis implemented on Model 3.
- Option 1b: RSA analysis results increased to match TOC overbuild's lateral capacity using Model 1.
- Option 2b: Interface force related TOC overbuild's lateral capacity combined with station's RSA results using the station's R_dR_o value of 1.95. Analysis implemented on Model 3.

Analysis results from all four cases, showing wall shears and storey forces below grade, are presented in Tables 5 and 6. These results indicate that design forces following option 2 are greater in magnitude than using option 1. Furthermore, the comparison shows forces based on the lateral capacity of the TOC overbuild provide greater strength than those based on RSA demands.

The overall finding of this comparison is that the proposed two-stage analysis, Option 2, is shown to provide results equal or greater than Option 1, which is the suggested approach for structures that don't comply with the stiffness requirements for the standard two stage analysis, as suggested in the commentary to NBCC 2015.

Table 5. Two Stage Analysis Comparison – Seismic Loads X-direction.

Analysis Approach	Basement Walls (Station) (kN)	Wall GL-DJ (TOC) (kN)	Elevator Walls (TOC) (kN)	Basement Walls (TOC) (kN)	Storey Shear (Basement) (kN)
Option 1a	5216	11929	1651	2950	20735
Option 2a	8968	13140	2466	3049	26016
Option 1b	12075	27610	3829	11062	48130
Option 2b	20855	30557	5735	7090	60502

Table 6. Two Stage Analysis Comparison – Seismic Loads Y-direction.

Analysis Approach	Basement Walls (Station) (kN)	Elevator Walls (TOC) (kN)	Basement Walls (TOC) (kN)	Storey Shear (Basement) (kN)
Option 1a	13512	2285	4677	18594
Option 2a	24692	2935	7480	33461
Option 1b	20232	3421	7003	27842
Option 2b	36854	4381	11165	49942

REPORTING RESULTS

The design interface loads resulting from the analysis are summarized through load schedules included in a set of drawings. These load schedules specify forces and moments associated with each connected element, using the table format presented in Table 7. Forces are provided unfactored for the following load cases: Dead - self weight, dead, live, wind, seismic and underground. The design of the station must use the provided loads through design combinations to develop a structure meeting strength, ductility, and serviceability requirements.

Table 7. Example Schedule Format for Interface Load Reporting

	DL					
Element	FX	FY	FZ	MX	MY	MZ
Ex.Col 1						

The seismic loads reported are based on the concept design TOC structure. In this instance, a seismic category SC3 and moderately ductile lateral force system were considered, and these parameters influence the reported results. The interface documents, however, do not define the seismic category of the overbuild. To provide context to the design loads, the R_d and R_o values are reported alongside the given return period of the earthquake. Additional documents are also shared which provide background geotechnical data used in the concept designs, which inform site class and shear wave velocity.

SUMMARY & CONCLUSIONS

In the protection of the station structure, it is critical to consider all aspects of the implementation of the TOC. Various interfaces exist between these structures and the interdependencies must be reviewed and considered in advance. In this study, the interaction between the structure's SFRS, the element connection locations, the capacity design requirements and the building movements are discussed. While these should not be considered the only relevant interfaces, they are noted as significant to the design in this case.

Seismic loads at the design interface are estimated through a sensitivity study varying the support conditions of the TOC overbuild. The results show the impact of the diaphragm stiffness on the overall shear demands in the TOC shear walls.

A modified two stage analysis approach is proposed, where the station is modeled as a separate structure with interface loads determined based on a model of the combined station and TOC structures. Analysis results show the approach is more conservative than option 1 recommended in the NBCC 2015 commentary.

ACKNOWLEDGMENTS

The authors would like to thank Infrastructure Ontario for supporting this initiative and SvN Architects + Planners for sharing reference material. The authors also acknowledge the contributions from the Building's Structures group at Mott MacDonald Canada Limited.

REFERENCES

[1] Ontario's Ministry of Municipal Affairs and Housing (2022). "Proposed Changes for the Next Edition of Ontario's Building Code (Winter 2022 Consultation)" online: https://ero.ontario.ca/notice/019-4974

[2] National Resource Canada – *NRC (2020) National Building Code of Canada 2020.* Prepared by the NRC, Ottawa, ON.

[3] Stanzeleit, J., Centeno, J., Firmo, A., and Pearce, M. (2023). "Seismic Design of a 27 Storey Transit-Oriented Community in Toronto" In *CCEE-PCEE*, Vancouver, British Columbia.

[4] National Resource Canada – NRC (2020) National Building Code of Canada 2020 Seismic Hazard Calculator. Online: https://www.seismescanada.rncan.gc.ca/hazard-alea/interpolat/nbc2020-cnb2020-en.php.

[5] Computer, and Structures, Inc. (CSI ETABS), 2022. Integrated Analysis, Design and Drafting of Building Systems, Berkeley, CA.

[6] Canadian Standard Association - CSA (2019). *CAN/CSA-A23.3: Design of concrete structures*. Prepared by the CSA, Toronto, ON.

[7] Canadian Standard Association - CSA (2014). *Explanatory Notes on CSA Group standard A23.3-14*. Prepared by the CSA, Toronto, ON.

[8] American Society of Civil Engineers. *Minimum Design Loads for Buildings and Other structures, ASCE/SEI 7-16*, American Society of Civil Engineers, Reston, VA, 2017.

[9] National Resource Canada – Structural Commentaries (User's Guide – NBC 2015: Part 4 of Division B). Prepared by the NRC, Ottawa, ON.