THE CONCRETE NZ CONFERENCE 2018
PROGRESS THROUGH COLLABORATION
Claudelands, Hamilton | 11 – 13 October 2018

WHAKATANE CIVIC CENTRE - PRACTICAL APPLICATION OF THE SIMPLE LATERAL MECHANISM ANALYSIS (SLAMA) FOR A DETAILED SEISMIC ASSESSMENT OF A CONCRETE FRAME BUILDING

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SUMMARY

The Whakatane Civic Centre is the headquarters for the Whakatane District Council (WDC) operations. It is a two-storey L-shaped building with an internal courtyard. The structural system consists of two-way concrete moment resisting frames on a foundation beam grillage over precast driven concrete piles. The frames provide support for a suspended double-tee precast concrete first floor and a timber trussed roof structure.

EDC reviewed the previous seismic assessments for the building and completed an independent detailed seismic assessment (DSA). Previous assessments had identified the building to be earthquake-prone with a seismic capacity of 8 *%NBS* for an Importance Level 4 (IL4) use, which is equivalent to 15 *%NBS* for an Importance Level 2 (IL2) use. This raised concerns within the WDC particularly as the building is intended to be the Civil Defence headquarters. We were advised that the WDC were not willing to continue occupying the building if the capacity was confirmed to be under 33 *%NBS* (IL2).

The Simple Lateral Mechanism Analysis (SLaMA) methodology was used to assess the likely building failure mechanism by examining critical load paths and their hierarchy of strength to determine the available ductility, damping and displacement capacity of the system. A three-dimensional ETABS analysis model assisted the hand calculations, particularly with the torsional building response given the L-shape plan geometry. Our assessment demonstrated the failure mechanism was expected to be soft-storey. The use of the SLaMA allowed us to refine the ductility and damping parameters which resulted in an improved seismic rating of 20-25 *%NBS* for IL4 and 35-40 *%NBS* for IL2.

When comparing with the previous IEP and DSA ductility parameters of μ=2.0 and μ=1.13 respectively, we learned that an improved understanding of the structure can substantially change the assessment parameters and outcomes.

This assessment provided confidence that the building was over 33 %NBS (IL2), and in accordance with the WDC directive, allowed continuous occupation for normal office use (IL2). The methodology described in the Seismic Assessment Guidelines produces reliable results, gives a good understanding of the failure mechanism, and most importantly, is straightforward in its practical application by structural engineers from a small consulting firm. Our findings represented good value for our clients by substantially saving in relocation costs and laying the foundations for future strengthening work.

INTRODUCTION

The Whakatane Civic Centre is located at the heart of Whakatane township and is currently used as the headquarters for the Whakatane District Council (WDC) operations.

History of the Building and Assessments

The building was designed in 1989 by Murray-North Limited and built in the early 1990's. A full set of the original architectural and structural plans was available for consultation.

Despite limited information on the original design parameters, it is considered the building was originally designed to category 2a of the loading requirements NZS4203:1984 (Code of practice for the general structural design and design loadings for buildings) with modifications from PW81/10/1:1976 (Code of Practice for Design of Public Buildings) and adhering to the design requirements of NZS3101:1982 (Concrete Structures Standard).

Category 2a buildings included civilian emergency centres and civil defence centres, therefore is equivalent to an Importance Level 4 (IL4) building in accordance with AS/NZS1170.

The building was first assessed using the Initial Evaluation Procedure (IEP) by another consultant in 2009 who scored the building to be 37 %NBS (IL4) assuming a ductility of μ=2.00. This preliminary assessment relied mostly on a site visit, review of the original plans, the year of construction and engineering judgment to achieve an overall rating without any specific calculations.

Further investigations were conducted and reported in the form of a Detailed Seismic Assessment (DSA) in 2015 which identified the building to be earthquake-prone with a seismic capacity of approximately 8 %NBS (IL4) considering a ductility of μ=1.13. This assessment relied on a site inspection including a floor level survey and specific hand calculations of the building's seismic capacity. This report included a strengthening concept and recommended further 3D analysis to complete the strengthening design.

An overall seismic capacity of approximately 14 %NBS (IL2) is inferred by scaling the DSA seismic rating to consider the building as Importance Level 2 (IL2) for normal office use. The earthquake-prone rating applies regardless of the building use.

Client's Position

While the WDC intended to use the building as the local Civil Defence headquarters (IL4), we were advised that the WDC were not willing to continue occupying the building for day to day activities if the capacity was confirmed to be less than 33 *%NBS* (IL2).

EDC was engaged to review the previous seismic assessments for the building and to complete an independent Detailed Seismic Assessment.

BUILDING DESCRIPTION

The following figures depict the overall structural system:

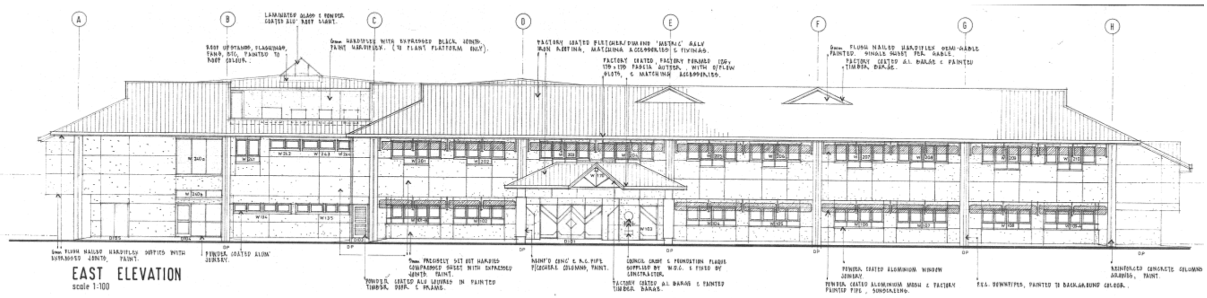

Figure 1 - East elevation

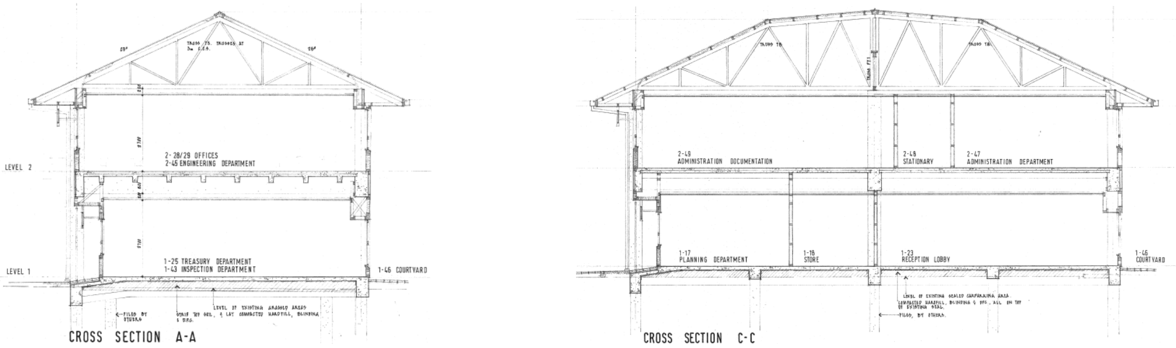

Figure 2 - Typical cross sections

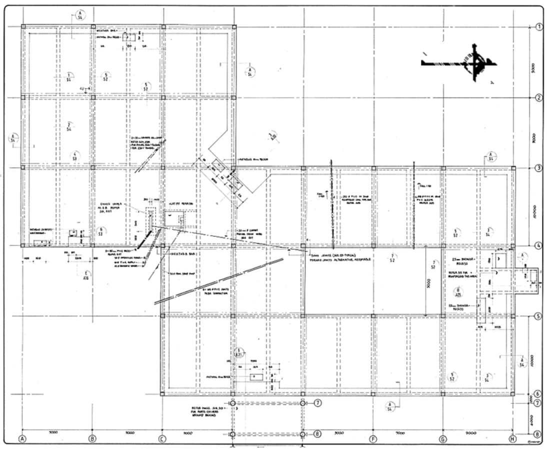
Figure 3 - Foundation plan

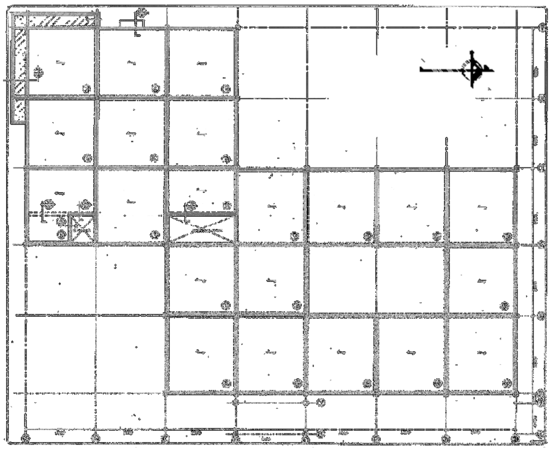
Figure 4 - First floor plan

The roof structure consists of lightweight profiled roofing cladding on timber framed trusses supported on cantilevered reinforced concrete columns extending up from the first floor.

First-floor construction consists of a 300mm deep flange-hung double-tee precast floor system with a 75mm topping spanning in the north-south direction between reinforced concrete beams. The precast flooring units have a 75mm seating on top of the beams. Some areas of the first floor consist of 150mm thick cast in-situ reinforced concrete infill.
The foundations consist of a 150mm thick reinforced concrete slab on compacted hardfill with a grillage of reinforced concrete ground beams spanning over precast concrete piles driven to between 8m and 10m below ground level.

For both orthogonal directions, the building has the same principal lateral load resisting system consisting of reinforced concrete moment resisting frames.

SEISMIC ASSESSMENT

A typical approach to assess the seismic capacity, and the approach adopted by the previous assessment, is to assume a low overall ductility for the lateral load resisting system based on engineering judgement. A linear pushover analysis would follow to determine the building's overall seismic rating.

To obtain a more accurate seismic rating, the displacement ductility of the critical section and of the global system could be determined using the Simple Lateral Mechanism Analysis (SLaMA) methodology.

SLaMA was first introduced in the NZSEE publication Assessment and Improvement of the Structural Performance of Buildings in Earthquake (NZSEE AISPBE:2006) as an analysis technique that allows estimation of the potential contribution and interaction of a number of structural elements and their likely effect on the building's global capacity. This procedure was further clarified in the updated document The Seismic Assessment of Existing Buildings issued in July 2017 (Seismic Assessment Guidelines).

The objective behind a SLaMA analysis is not to rely on sophisticated techniques without first developing an understanding of how the building resists seismic loads, while identifying critical load paths and how the various systems might interact.

Assessment Methodology

While assessing this building, we utilised the SLaMA procedure as a first step to assist us in defining the hierarchy of strength of the structural elements, the probable mechanism of collapse and the available displacement ductility of the structural system. The procedure followed the steps outlined in the guidelines and is summarised below:

[Step 1] We assessed the structural load path configuration and identified any potential structural weaknesses. For this building, the seismic loads are distributed by the roof and first floor diaphragm to the moment resisting frames. We identified potential structural weaknesses such as column or beam failure, beam elongation and precast floor seating failure.

[Step 2] Probable capacities of key beam, column and beam/column joint sub-systems were calculated using first principle section analysis assisted by the Response2000 software and the formulas presented in the guidelines. This step identifies if the likely failure mechanism is flexural or shear related. For this building, the failure mechanism was found to be a flexural failure (ductile).

[Step 3] The probable inelastic mechanism of the sub-systems was determined by comparing probable member shear capacities, thus evaluating the hierarchy of strength. The hierarchy of strength at each beam/column joint is established by comparing the strength ratio of the interconnected components. This assessment step for this building resulted in limiting the external beam/column joint bending capacity relative to the maximum joint shear capacity.

[Step 4] The sub-system inelastic mechanism was assessed for moment frames, using the Sway Index, by extending local to global behaviour. Likely failure mechanism of post-elastic deformation due to severe earthquake forces was identified to be flexural failure of the columns at the lower floor, with an undesirable soft-storey collapse mechanism.

[Step 5] We calculated the probable base shear and global displacement capacity. Given this structure only has one sub-system in both orthogonal directions (concrete moment frames) the base shear calculation is dependent on the likely failure mechanism and can be summarised as the sum of the column moment capacities over the column effective lengths. The assumed rigid first floor diaphragm made it necessary to consider torsional amplification effects arising from the mass and strength/stiffness eccentricities inherent to the building plan irregularity. Method B in Appendix C2F of the assessment guidelines was considered for the inelastic torsional response of a ductile system in both orthogonal directions which provided the increase in base shear. Having identified the likely failure mechanism and critical sections (columns at ground floor), the probable displacement capacity of the critical column section was calculated and compared to the limits defined by bar buckling and lateral yield displacement at the first level. This resulted in a global structural displacement ductility for the system of μ=1.9.

[Step 6] The final step of the SLaMA procedure is to determine an equivalent single degree of freedom (SDOF) system, the seismic demand, and a displacement based %NBS. For the SDOF system, an effective height and mass are calculated. As the seismic demand is dependent on the damping being considered for the system, an inherent damping of 5% was considered along with additional damping due to the structural system being considered, the materials and levels of hysteretic energy dissipation. An equivalent system damping of $\xi=15\%$ was determined. By plotting the NZS1170 response spectrum curves in the form of an acceleration/displacement response spectrum (ADRS) for the required building importance level and system damping, an Ultimate Limit State (ULS) displacement can be found, refer to Figure 5. This leads to a preliminary *%NBS* score for the system based on the ratio of the spectral displacement at ULS and the probable displacement previously determined.

For an Importance Level 2

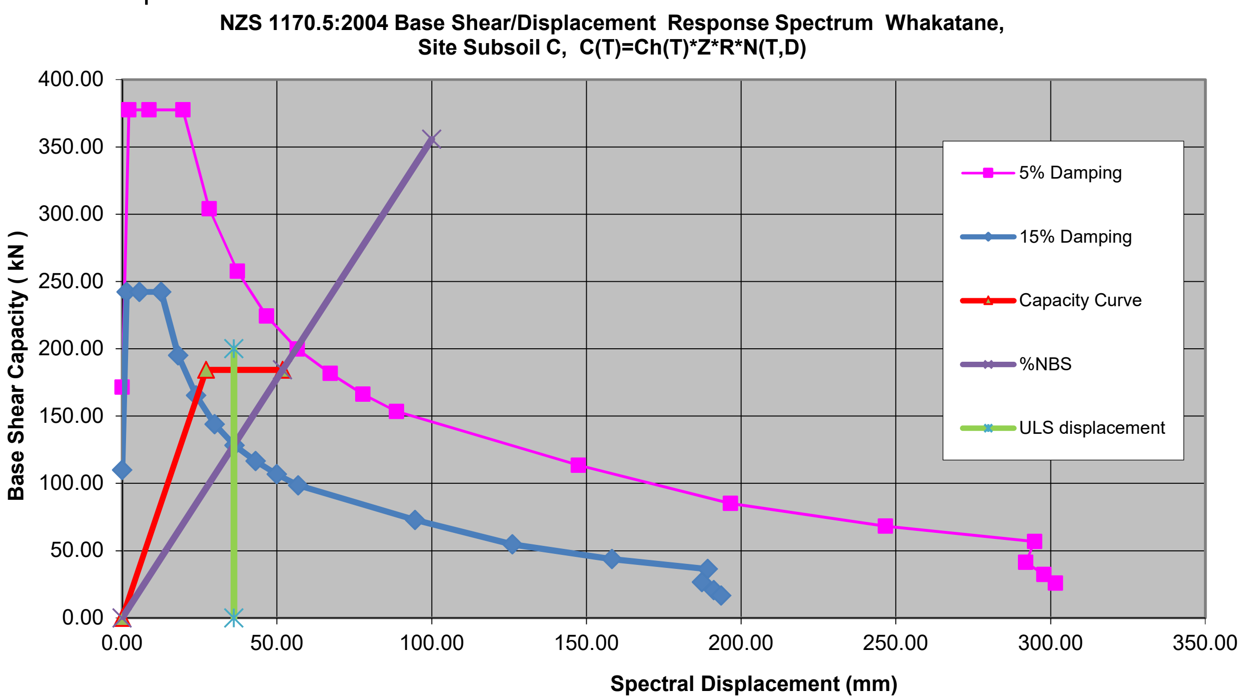

Figure 5 – ULS displacement for IL2

<u>Force-Based Assessment Results</u>

The results from the SLaMA analysis were applied to a 3D model of the building using the finite element software package ETABS to determine the maximum demand on each of the structural elements. An analysis of critical sections for flexure and shear was conducted and a final %NBS score was achieved for each of the demand levels (importance levels) being considered. The building was scored to be at 20-25 %NBS (IL4) and 35-40 %NBS (IL2).

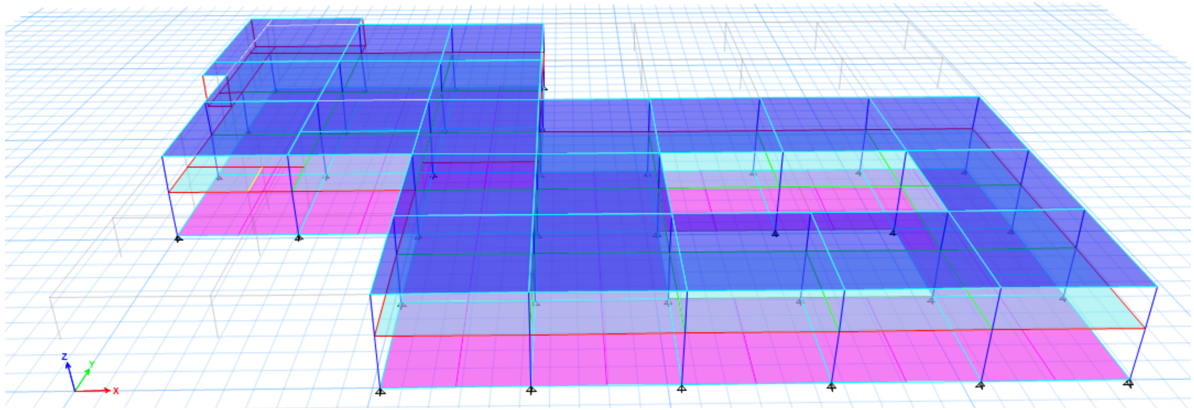

Figure 6 – Three-dimensional ETABS model

Seismic Assessment Outcomes

The SLaMA analysis procedure showed that a soft-story collapse was the likely failure mechanism of the building (the Critical Structural Weakness), with an allowable displacement ductility μ=1.9 and an equivalent damping of $\xi=15\%$ suitable for the system.

When comparing with the previous IEP and DSA assumptions of μ=2.0 and μ=1.13 respectively, we learned that an improved understanding of the structure can substantially change the assessment parameters and outcomes. This is a significant benefit of applying the SLaMA analysis procedure to a building of this nature, as it provides with a good level of confidence the design parameters that have a direct impact on the buildings seismic rating.

The SLaMA procedure relies on specific first principles section checks to determine probable capacities and provides a better understanding of the hierarchy of strength and probable failure mechanisms. More accurate assumptions and reduced conservativeness result in more reliable *%NBS* scores.

The SLaMA is an iterative and time-consuming procedure with potential for errors from even experienced engineers. It requires a good understanding of engineering first principles and seismic assessment experience. The use of programs such as Mathcad, Excel and Response2000 can streamline the iterative procedure and substantially reduce the assessment time.

CONCLUSIONS AND RECOMMENDATIONS

The use of the SLaMA is as its name suggests, simple. Despite being a labour-intensive process, the SLaMA methodology is an effective tool for practicing engineers. Sure, there is a heavy calculation load, but this can be automated using software like Mathcad and Excel. The SLaMA procedure is prescriptive which is advantageous when other engineers peer review an assessment.

In this instance the additional effort invested in developing the SLaMA rewarded us with a more accurate understanding of the building's likely behaviour in a severe seismic event. The assessment gave us the confidence to adopt higher ductility and damping parameters than we normally would consider, resulting in a higher %NBS rating. According to the brief and WDC directives, the refined assessment results allowed continuous occupancy of the building thereby saving substantial relocation costs with equipment and staff.

ACKNOWLEDGMENTS

I would like to acknowledge Dave Brunsdon for his support during the assessment review stage.

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