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Comparison of Earthquake Loads and Wind Loads for Low and Mid Rise Concrete Buildings with Respect to Ductility Requirements and Reinforced Concrete Detailing

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Abstract

When designing lateral load resisting systems for low and mid rise concrete buildings it is common practice for structural engineers to use AS1170.2 and AS1170.4 to perform a quick calculation of the static wind and earthquake loads expected to act on the structure. From the base shears and overturning moments obtained the designer then determines the governing load case and proceeds with detailed design. There is often little consideration given to the notion that structures behave differently under the two load cases. While structures are typically designed to remain elastic under wind loading, it is standard practice to allow structures to behave inelastically under earthquake loading, thus placing a higher importance on detailing for earthquake governed structures. Situations may arise when a building is governed by wind loads for strength; however, due to the ductility demands under earthquake loads the drift is also critical. If the designer were to focus only on wind loads after the initial comparison, the building may be inadequately detailed for earthquake loads leading to significant failure in the event of an earthquake. By presenting a case study of a mid rise building, this paper aims to highlight the need for appropriate detailing in reinforced concrete buildings for earthquake loads with respect to ductility requirements.

Keywords: Ductility requirements, low and mid rise concrete buildings, earthquake loads, reinforced concrete detailing

1. INTRODUCTION

Lateral load resisting systems are an important consideration in the design of multi-level structures. The lateral loads that are typically designed for in Australia are; earthquake loading, wind loading and robustness. It is common practice to simplify these as static point loads acting at each floor level. However, the structural behaviour of a building may vary greatly under different types of loading even with an equivalent magnitude of base shear. This is due to the inherent differences between earthquake and wind loading and the assumptions made during the design process. Historically, Australian designers have focused on wind loads as they are easier to predict than earthquake loads and are arguably more intuitive. While structures are typically designed to remain elastic under wind loading, it is common practice to allow structures to behave inelasically under earthquake loading. This assumption places greater importance on detailing of the structure with respect to ductility requirements. This paper presents a comparison of wind and earthquake loads acting on a building and aims to highlight the need for appropriate detailing in reinforced concrete buildings for earthquake loads with respect to ductility requirements. For the purpose of this paper mid rise buildings are described as those between four and twelve stories.

2. FORCE BASED STATIC EARTHQUAKE LOADS AND STATIC WIND LOADS TO AS1170.4 AND AS1170.2.

2.1 STATIC EARTHQUAKE LOADS

When a seismic event occurs the shaking of the ground causes lateral inertial forces to act on a building. To estimate the loading induced by this inertial response there are several procedures that can be used. One common approach to earthquake design is the equivalent lateral force approach or static method. This involves a simplified calculation of the lateral base shear based on an estimate of the structures fundamental period, likely acceleration response for a particular soil type and the importance level of the structure. Once the maximum base shear is obtained, horizontal loading that is equivalent to this shear is distributed throughout the height of the building.

AS1170.4 gives the following equations to determine the static earthquake forces.

$$T_1 = 1.25k_t h_n^{0.75} \qquad \text{Cl 6.2.3} \qquad [1]$$

$$V = C_d(T_1)W_t \qquad \text{Cl 6.2.1} \qquad [2]$$

$$F_i = k_{F,i}V \qquad \text{Cl 6.3} \qquad [3]$$

where all parameters are as given in the code

Another prevalent method is the dynamic or modal analysis procedure. This involves the use of an earthquake design response spectrum and modal analysis of a lumped mass model of the building in order to obtain the modal shapes and frequencies of vibration (*Stafford Smith, 1991).* The dynamic method is not the focus of this paper and is not discussed in great detail.

2.2 STATIC WIND LOADS

Static wind loads are determined by estimating the wind pressure acting on the buildings exterior and by calculating the equivalent point load applied at each level at the centre of area. The code makes provision for relevant terrain category, topography, shielding from adjacent buildings as well as leeward and windward suction co-efficients.

AS1170.2 gives the following equation to determine the static wind pressures, which are then multiplied by the exposed building area to obtain a force.

$$\rho = (0.5\rho_{air})[V_{des,\theta}]^2 C_{fig} C_{dyn} \qquad \text{Cl 2.4.1} \qquad [4]$$

where all parameters are as given in the code

2.3 DIFFERENCE IN DESIGN PHILOSOPHY BETWEEN EARTHQUAKE GOVERNED BUILDINGS AND WIND GOVERNED BUILDINGS

Earthquake loading and wind loading differ in a number of ways, and as such the design considerations for each loading case may be different. Earthquake loads are highly dependent on the mass of the structure and distribution of the mass. A structure with a higher mass will attract higher earthquake loads, however wind loads will remain the same for the equivalent exposed area regardless of change in mass. This should be considered when determining gravity load resisting systems such as composite steel frames (generally lighter) or prestressed/conventional reinforced concrete (generally heavier). The stiffness of the structure and the soil conditions will also impact the earthquake forces but not the wind loads developed.

One key point of difference between the two loading cases, that is not well understood by many practicing engineers, is that the earthquake design base shear is less than the actual shear expected to act on the building during an earthquake. The force is reduced to account for the ability of the structure to remain ductile as members yield and displace beyond their elastic limits and for the overstrength of materials. This is not the case for wind loading, and as such for an equivalent base shear force different displacements can be expected.

3. IMPLICATIONS FOR DESIGN OF LOW TO MID RISE BUILDINGS

Seismic loading typically governs lateral design over wind loading for low to mid rise buildings due to the structures increased stiffness. Care must therefore be taken when selecting a ductility class for design. Cl 6.5 of AS1170.4 allows the designer to use a structural ductility (μ) of up to 3 and a structural performance factor (S_p) of 0.67 for ductile shear walls (Table 6.5(A) AS1170.4). For conventional reinforced concrete buildings this is commonly adopted in design. This equates to reducing the equivalent static force to 22% of its unfactored value resulting in an extremely large displacement demand of 4.5 times the elastic drift (Cl 6.7.2 AS1170.4). Such a large displacement demand requires specific detailing and in many cases may be difficult to achieve.

3.1 DRIFT COMBATIBILITY

Drift compatibility is another item that is often overlooked (*SRIA, 2016*). While a designer may like to assume the full seismic load is resisted by shear walls and is not relying on columns or frame action, these elements must be checked to ensure that they can withstand the displacement demand that is expected occur. Particular care should be taken when using precast columns or floor systems. While AS1170.4 does not explicitly preclude the use of ductility class 3 for precast structures, it is generally recommended (*SRIA, 2016*) that the designer should adopt a lower ductility factor.

4. CASE STUDY

A typical residential building has been chosen as a case study for analysis. Namely, a 12 story reinforced concrete building located in Sydney, Australia with three shear cores. The building also consists of several podium levels. A static analysis has been undertaken as a preliminary check. The analysis software ETABS 2015 has been used.

The figures below indicate the buildings configuration and relevant design parameters.

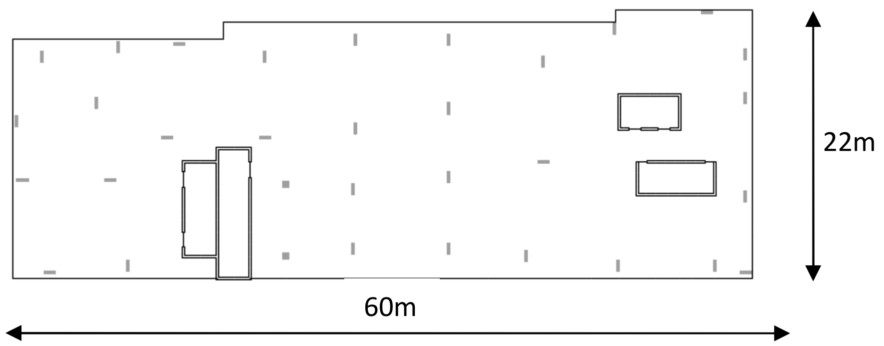

Figure 1: Typical Floor Plan

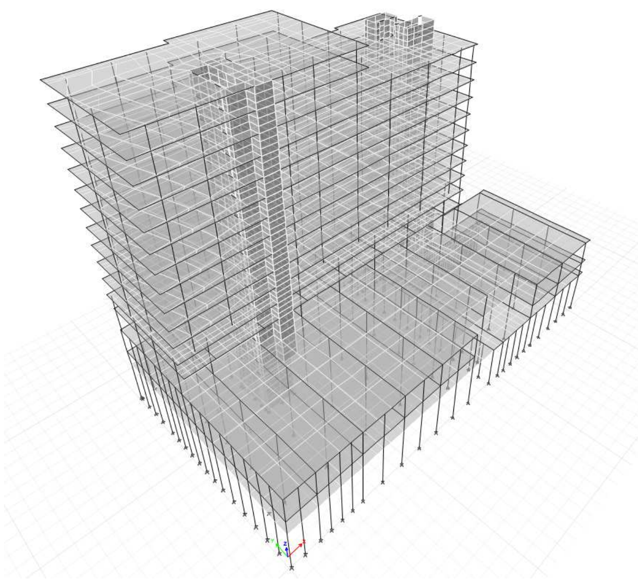

Figure 2: Isometric View

Design Parameters;

Ductility, μ = 3

Structural Performance factor, S_p = 0.67

Seismic Hazard Factor, Z=0.08

Importance level 2

Soil Class Be (rock)

Terrain category 3

Design wind speed 45m/s

Shielding, topography, and directional modifiers, 1.0

4.1 RESULTS AND DISCUSSION

The following table summarises the results obtained from the ETABS model in the north/south (Y axis) direction.

RESULTS	**Earthquake**	**Wind**
Base shear, Y (kN)	3600	3800
Overturning Moment, Y (kN)	135,000	140,000
Elastic Drift at Roof (d_{ie}), Y (mm)	27	45
Inelastic Drift at Roof, Y (mm) ($d_{ie}\mu/S_p$)	120	-
Fundamental Period (s)	1.8	

From the above summary of results, it can be seen that the building experiences a similar, but slightly larger base shear force and base overturning moment under wind loading when compared to earthquake loading. However, due to the ductility assumption used when calculating the earthquake forces the drift is greater under earthquake loading than under wind loading. This is important to note and is often overlooked in practice. Had the designer just undertaken a quick manual calculation of base shears and overturning moments and compared the two load cases and deemed wind as the governing load case, the structure may not be detailed adequately to achieve the ductility level that has been assumed. As discussed in section 2.3 of this paper, the ductility assumption allows the design forces to be reduced. If a lower level of ductility is applied, then the force is increased. Such an increase is likely to increase the base shear and overturning moment resulting in larger design actions than those generated by wind loads. This could have a significant impact on the design of the lateral load resisting elements. Given the somewhat irregular nature of the building a dynamic analysis would be recommended for final design once a preliminary understanding has been obtained using the static analysis.

For a building of this nature, not detailing adequately for ductility could potentially lead to brittle failure of shear walls around openings due to a lack of confinement to concrete around boundary elements or potential for punching shear failure of slab and column joints.

5. CONCLUSION/ RECOMMENDATION FOR FURTHER RESEARCH

- Structures behave differently under earthquake loads and wind loads. Current design procedures assume that the structure will experience inelastic behaviour under earthquake loading, however remain elastic under wind loading.
- The differences in ductility assumptions between earthquake loads and wind loads are not well understood by many practicing engineers in Australia. AS1170.4 does not give a detailed explanation on applicable use of ductility class which can result in designers placing inappropriately high displacement demands on structures which are then not adequately detailed resulting in potential for increase in earthquake damage.
- It was observed that for similar base shear and overturning moments the displacement demand on the building was greater under earthquake loads than under wind loading. This highlights the need to carefully select an appropriate ductility level and detail the structure accordingly.
- Engineers should consider both load cases independently particularly for buildings when a high ductility class is assumed, to ensure that a conservative design is adopted. This is particularly evident for low to mid rise buildings as the increased stiffness creates greater susceptibility to earthquake loads.
- The code could be updated to include further explanation and guidance on suitable ductility classes. It is not uncommon to see practicing engineers attempt to design buildings with precast cores or floors as fully ductile without providing adequate detailing.

6. REFERENCES

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