PRACTICE NOTES ARISING FROM CONTRAVENTION OF ECSA's RULES OF CONDUCT FOR REGISTERED PERSONS.

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Practice Note No. 2015/1:

THE IMPORTANCE OF TAKING SEISMIC LOADING ON A BUILDING STRUCTURE FULLY INTO ACCOUNT

THE PROJECT

An apartment building of 15 levels including 2 lower levels for parking, constructed in concrete, with reinforced concrete columns, lift shaft walls and post-tensioned flat slab floors, supported by piled foundations. The building was constructed between 2003 and 2005, in a coastal environment.

BACKGROUND

The design of the building structure considered the effects of seismic loading, but this was to a limited extent, which resulted in the design being deficient in the ability of the structure and foundations to withstand lateral applied seismic and wind loads. The design engineer was called to face an ECSA disciplinary hearing, dealing with contravention of ECSA's Rules of Conduct arising from alleged faulty and inadequate design.

In keeping with ECSA's policy for Practise Notes to reduce the risk of recurrence of mishaps and contravention of its Rules of Conduct, this note examines the design to identify its deficiencies and demonstrate what would be a correct course of action through the section below on Lessons to be learned.

DETAILS OF THE PROBLEM

The building occupied a rectangular footprint on plan, being 42m long by 18.8m wide. A core, containing the lift shaft and staircases, surrounded by reinforced walls and approximately 7m by 4m in plan, was located midway along the length of the building, **external to it**. This formed the main means of withstanding lateral loading and transferring such loads to the ground. The design was examined by two experts, the first in 2005 and the second in 2010.

The 2005 investigation concentrated on seismic loading, and resistance of the structure to seismic forces in SABS Zone 1 region, being Cape Town. The provisions for earthquake loading in the loading code for buildings, SABS 0160 were applied. Thereby the equivalent static pushover force method was followed, computed as described in SABS 0160 from the total permanent vertical load (weight) plus 30% of the live load.

A detailed calculation gave a total weight W = 98.3kN. The first natural period of the building was computed through the simplified prediction models of SABS 0160 and from the prescribed acceleration for Cape Town region (Zone 1) = 1 $m/s^{2.}$ This gave the total base shear at the base of the building V_b = 0.04W = 3.93 kN, with a “behaviour factor” K = 5 for a building with an RC shear wall. Using equations in SABS 0160 the vertical distribution of the total shear up the height of the building was calculated at each floor, ranging from 0.44 kN at the roof to 3.93 kN at the base.

The structural system for earthquake resistance is that of a shear wall, comprising the staircases and lift shaft. Its resistance cannot be combined with that of the RC columns, due to the large difference in stiffness. If the resistances are combined the shear wall will reach its capacity (which is less than the required total resistance) at relatively small deformation, due to its stiffness. At this low deformation insignificant column resistance relative to its capacity will exist. Beyond this level of deformation the column resistance will increase, but that of the shear wall will reduce significantly. The total resistance will not arise simultaneously, whereby failure is imminent under such earthquake excitation.

By considering the total length of shear wall in each orthogonal direction of resistance, the average shear stress in the wall was computed as 2.2 MPa in the longitudinal direction and 1.2 MPa in the transverse direction at the level 2, above the parking garages. The maximum allowable shear stress in RC elements when including significant levels of shear reinforcement is approximately 5.5 MPa. Even with a behaviour factor of K = 2 for a framed RC building the maximum shear stress is lower the maximum shear capacity.

However, due to the extreme eccentricity of the lift shaft shear wall system, being on the outside of the building with regard to its centre of gravity, rotation will occur in the case of longitudinal excitation. The eccentricity is the distance between the shear centre of the shaft and centre of gravity of the building, of which the inertia is the mechanism of loading during seismic action. The eccentricity was calculated to be 8.74m, leading to a torsion moment T = 33.68 MNm at level 2 of the building. This causes a maximum shear stress of 85 MPa in the wall. Allowing for redistribution of stress in reinforced concrete, with a plastic deformation considered in the extreme and with proper reinforcement detailing, a maximum shear stress of 3.8 MPa results with K = 5 and 9.5 MPa with K = 5.

In addition the restrained warping that will accompany the torsion rotation of the extremely eccentric shaft will cause additional normal forces in the corners of the shear walls which place additional requirements on the piling resistance and foundation design.

It was concluded that overall the building was unfit to resist seismic action to the level of Zone 1 (Cape Town) due to the eccentricity of the shear wall system. The placement of shear resisting elements such as properly tied in RC shear walls, should reduce the eccentricity of the shearing resistance system, to reduce the torsion action accompanied by transverse earthquake excitation.

The 2010 investigation was done at request of ECSA during the disciplinary hearing into the conduct of the design engineer. The focus was on the stability of the lift shaft core and its piled foundations.

The lateral loads, and average floor loading were the same as in the 2005 report. As the shaft core stiffness constituted 91% of the lateral stiffness of the structure it was assumed to resist all the lateral loads on the structure. The design seismic load (N-S and E-W) was calculated as 119 MNm. The design resistance of the core was found to be 61 MNm (N-S) and 32 MNm (E-W). With a factor of safety for overturning of 1.5 the design resistance was significantly less than the required 178.5 MNm

Wind loads were calculated for a terrain category 2. The design wind load (N-S) was calculated as 18MNm and 40 MNm (E-W). The design resistance of the core was found to be 61 MNm (N-S) and 32 MNm (E-W). For lateral stability the required design resistance should be a minimum of 27 MNm (N-S) and 60 MNm (E-W) based on a factor of safety for overturning of 1.5

For an analysis of the strength of the core foundations – specifically pile capacity, it was assumed the critical load case was with the seismic and wind loads applied in the E-W direction. Due to the severe nature of the overturning moments on the base, the full tension capacity of the 600mm diameter continuous flight auger (CFA) piles could be utilised in determination of the design resistance for overturning. Each pile had a compression capacity of 1400 kN and tension capacity of 420 kN. The lever arm between a compression and tension pile was 3.1m. The results of this analysis were as follows:

Compression pile:	Design load/pile	Design Resistance/pile
Seismic loading	12 000 kN	1 400 kN
Wind loading	5 620 kN	1 400 kN
Tension pile:		
Seismic loading	4 330 kN	420 kN
Wind loading	1 140 kN	420 kN

The extents to which the design loads exceed the resistance of an individual pile are alarming. While design loads will only occur in a seismic event and may not be immediately realised, wind loading can occur regularly. In this case infill masonry panels could likely be aiding the structure's resistance, but this is not common practice.

The above findings clearly show that the design considered was insufficient to resist seismic loads as prescribed by SABS 0160: 1989, being the applicable code at the time. The findings also demonstrated that the designer of the structure failed to engage and adhere to acceptable practices and the design was undertaken in a manner that could endanger public safety.

WHAT LESSONS CAN BE LEARNED?

A number of lessons to be learned exist in three main areas:

1. In design of a high rise building structure to resist seismic loads:

1.1 The elements resisting the seismic force, such as shear walls and cores, should be placed with symmetry in the building envelope. This is intended to reduce the development of secondary torsional loads on the structure. For example, a building which is rectangular or oval in plan should have its core placed at the centre, and not on the outside, of the plan shape.

1.2 The core should be situated in a manner to ensure it maximises the amount of vertical load that it sustains. This increase in vertical load is beneficial to the overall stability of the core, as this load aids the resistance to overturning caused by the applied seismic loads. Placing the core towards or at the outside of the building causes it to be eccentric to the main floor slabs and as such it resists a greatly reduced vertical load than a core which is central to the building.

1.3 The shape of the core is also critical to the overall capacity to sustain the applied loads. The use of shapes such as T, L and H will result in an increased and concentrated stress state at the open corners of the core. It should ideally be constructed as a closed box to gain the maximum benefit for any torsional load and result in an even stress distribution. The provision of a U shaped eccentric core is not an efficient structural solution.

2. In risking charges of contravening ECSA's Rules of Conduct:

Arising from professional negligence, the designer could be charged with contravening:

2.1 Rule 3(1)(a), to discharge his/her duties to his/her client and the public effectively with skill, efficiency, professionalism, knowledge, competence, due care and diligence.

2.2 Rule 3(1)(b), undertook work of a nature for which his/her education, training and experience have not rendered him/her competent to perform.

2.3 Rule 3(1)(c), failed to engage and adhere to norms of the profession.

2.4 Rule 3(3)(a), did not have due regard for and give priority to the health, safety and interest of the public.

3. In looking to the future:

3.1 Seismic activity is on the rise generally and the new RSA seismic map affects a much larger area of the country than previously.

3.2 Brick piers and small concrete columns cannot be relied on exclusively to provide lateral restraint against seismic loading.

3.3 Soft storeys in buildings (especially at ground floor, must be avoided).

3.4 A major side effect of fracking, often ignored, is the localised increase in seismic activity in the areas where this is done.

3.5 The Western Cape is an area where seismic issues need to be addressed with some caution.

3.6 Designing for seismic action in RSA is not terribly onerous but does need to be considered by the Structural Engineer. The simple 10% of vertical load as a horizontal force at each level will normally more than suffice to account for seismic loading. It is not essential to do hi-tech seismic analysis as is required in California, Japan and other seismic sensitive areas of the world.