THE LARGEST BASE-ISOLATION PROJECT IN THE WORLD

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ABSTRACT :

The paper explores in detail the peculiar technical, economical and social issues related to the use of base isolation in huge housing projects. The effectiveness of the base isolation in the protection of typical construction systems is illustrated. The paper reports on a significant large housing project currently under construction, for which the structural design has been carried out by the authors. Hypotheses of different structural variants are reported focusing on their cost effectiveness.

KEYWORDS: Seismic isolation, base isolation, housing project

1 INTRODUCTION

Huge public and private housing programmes are nowadays in progress in several developing countries, many of which located in high seismicity areas (China, Iran, Northern Africa, etc). The realisation of large settlements calls for the use of industrialised, prefabricated or cast in situ construction systems. Usually, the structural systems resulting from the use of the aforesaid technologies are characterized by poor seismic performance, related to the structural members' typology (i.e. walls) and to the presence of critical elements (i.e. joints).

Seismic (or base) isolation is a design technique that reduces the force demand on structures by isolating them from the damaging effect of the ground motion. It functions primarily by lengthening the period of the structure. This approach contrasts with conventional design schemes that rely on inelastic action of various structural elements to dissipate earthquake energy. Isolation reduces the force demand on the structure and thereby limits inelastic deformation; it provides a level of performance well beyond the normal code requirements with potential for substantial life-cycle cost reduction. In contrast to conventional technology, seismic isolation offers the possibility of protecting the contents and secondary features of the building because seismic forces transmitted to the structure are reduced. There has been much emphasis on the suitability of base isolation for critically important structures such as hospitals and emergency centres. For such buildings where protection of contents is critical, either because of their value or because of the need to maintain serviceability after an earthquake, seismic isolation can be an attractive option both technically and economically. The protection of both structure and contents, however, would be advantageous for ordinary civil structures, such as apartment blocks, particularly in areas of high seismicity. Settlements of large size help justify and make economically beneficial the adoption of base isolation. As a matter of a fact, the high number of seismic isolation devices to be used allows for a reduction of their costs (short-term saving). Furthermore, when base isolation is adopted for an entire settlement the lower seismic vulnerability can impact on the surrounding region. Last but not least, the high level of protection given by the seismic isolation assures the almost complete absence of damage and thus the avoidance of post-earthquake repairing costs, even for the design earthquake, whose probability of occurrence during the structure lifetime is significant in highly seismic areas (long-term savings).

The structural designs presented in the paper were commissioned from the authors by the developer; the authors, however, have not been involved in the construction on site.

2 GENERAL DESCRIPTION OF THE PROJECT

The project, undertaken by a Malaysian group of investors for the Iranian Ministry of Housing and Urban Development, is part of a huge housing program currently running in Iran and foresee the construction of a new township with almost 10,000 units of residential apartments, shopping centers, schools and mosques. The development, located in the Parand New Town, 35km south west of Tehran, close to the new Iman Kohmeini International Airport, will cover an area of 160 ha. The overall cost of the project is estimated to be around US$250 millions. In the new town master layout (Figure 1), that will be implemented in several phases, use is made of five types of buildings having different layout, heights and dimensions; in Figure 2 some perspective views of the different building types assembly are reported. A similar project is planned in Hashtgerd new town, 65km from Tehran.

Due to the high seismicity of the area and to the lack of specific studies, an expected PGA of 0.35g was assumed for a return period of 475 years with an amplification soil coefficient S=1.2. After preliminary designs aimed at comparing conventional and innovative seismic design approaches in terms of costs and benefits, it was decided to adopt, for all the 10,000 units, the base isolation technique.

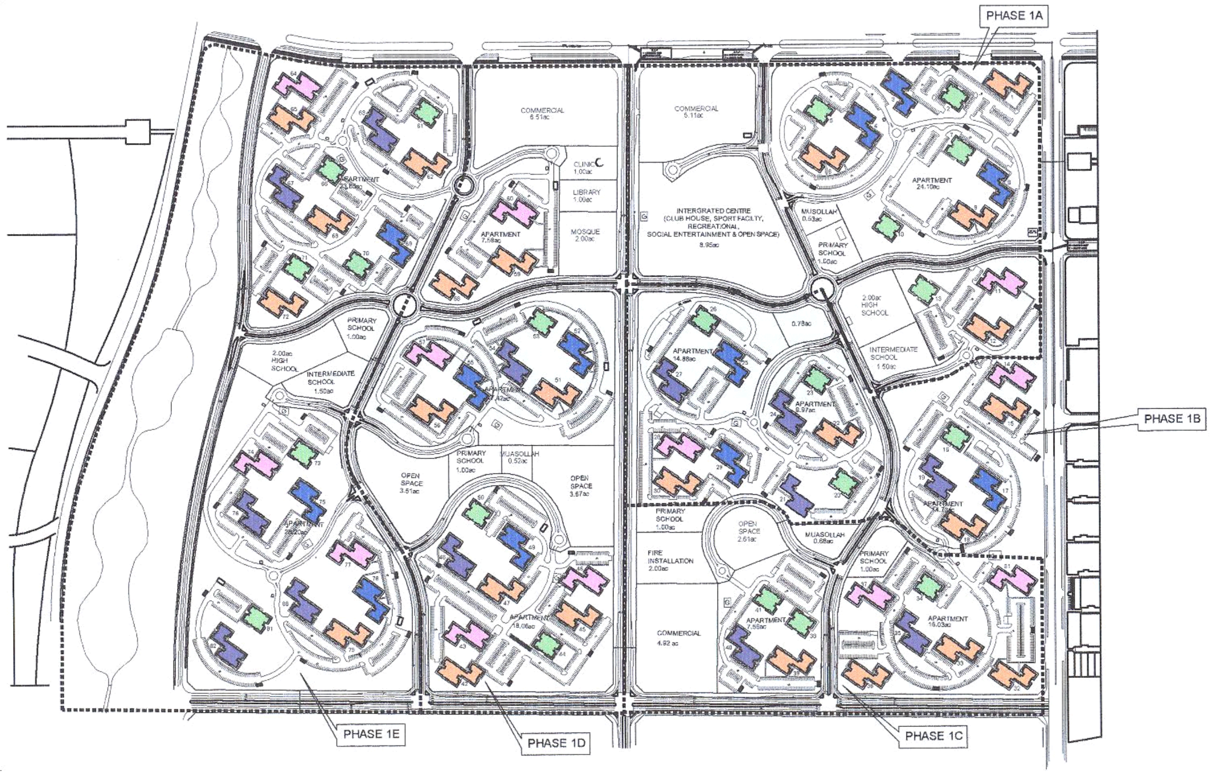

Figure 1 Master layout and phasing

Figure 2 Assembly of blocks

2.1 Buildings' typologies

As previously stated, different buildings types (blocks) are foreseen in the Parand base isolated new town; the schematic layout of all of them is given in Figure 3; Table 1 summarizes their characteristics and Figure 4 shows virtual views of the 12 (Type A) and 8 (Type B1) storey buildings. Dimensions of the blocks vary from 90 to 100 m^2. It has to be noted that the Figure 4 shows a 5 storey Type B building, as it refers to the initial design stage. Actually, during the design activities, the developer decided to increase up to 8 storeys all the building of Type B. Blocks B1, B2, B3 and B4 consist of 2 parts, referred to as "main" and "minor", separated by a structural joints.

Figure 3 Building typologies

Table 1 Characteristics of the buildings types

Block type	n° of storeys	n° of units/block	n° of blocks
A	12	71	21
B1	8	96	24
B2	8	96	12
B3	8	96	12
B4	8	96	13

Figure 4 Virtual view of Type A (left) and Type B (right) buildings

2.2 First phase

The first phase (phase 1A) of the base isolated Parand new town project started in May 2007 and involved the design of 4 different types of buildings, namely 5 blocks of "Type A", 4 blocks of "Type B1", 3 blocks of "Type B2" and 1 block of "Type B3", for a total number of 1052 dwelling units (Figure 5). Construction works started in September 2007 and the first isolators were installed in November 2007.

Considering the huge development, the opportunity was taken during the first phase to fine tune the design. Feasibility studies were carried out to determine the optimum location and characteristics of the isolation devices. Calculation procedures and tools were implemented to speed-up the re-check operations. The on-site operations, concerning the installation of the devices, were adjusted according to the needs coming from the actual construction works and from the on-site environmental conditions during the different seasons.

Figure 5 Layout of the first phase

3 STRUCTURAL CONFIGURATION AND ISOLATION LAYOUT

From the structural point of view, the buildings, in their initial configurations, are characterized by the presence of r/c shear walls in both longitudinal and transverse directions. This kind of structural system was requested by the developers, owing to their familiarity with it, at least when built with traditional casting. Analyses showed that a wall system can be effectively isolated, but, due to its construction characteristics, the isolation does not allow a reduction of the structural materials and thus of the direct construction costs.

Due to the lack of specific Iranian norms for the design of base isolated structures, reference has been made to the European Codes for earthquake resistant (CEN, 2004a) and reinforced concrete (CEN, 2004b) structures. Three dimensional mathematical models of the structure were implemented in the computer code ETABS. In the Finite Element (FE) models a detailed description of structural elements and mass distribution have been taken into account. Using a linear elastic structural model, a series of FE seismic analyses were performed using the response spectrum method to evaluate the performance of both the isolation system and the structure. Further analyses, which allowed non-linearities in special elements representing the characteristics of the isolating devices, were also carried out. Results from the latter confirmed those obtained from the linear analyses.

3.1 Wall system

The layout of the wall system, along with the isolators layout, is illustrated in Figure 6, for the12-storey “Type A” building (for the sake of conciseness similar details for the other buildings types are not presented here). The main walls are 200mm thick at their base, a section reduction at the higher storeys results in a minimum thickness of 160mm. Walls that are too thin can complicate the construction operations, negating the small reduction of material costs. Each wall is isolated with two or three devices, so requiring a stiffening beam at its base (Figure 7). These beams act as ties with respect to the arches formed by the lines of compressive stress as these flow towards the bearing supports. The core portion of the building, including the lift and their pits, is completely suspended from the upper part to avoid the need to accommodate horizontal movement. This problem does not arise with the stairs, that end at the ground floor because there is no basement. All the floor decks consist of r/c slabs having a thickness of 150mm. A perimeter cantilevered slab (Figure 7) is provided for covering the perimeter gap required by the movement (±233mm) of the isolated building under the design earthquake.

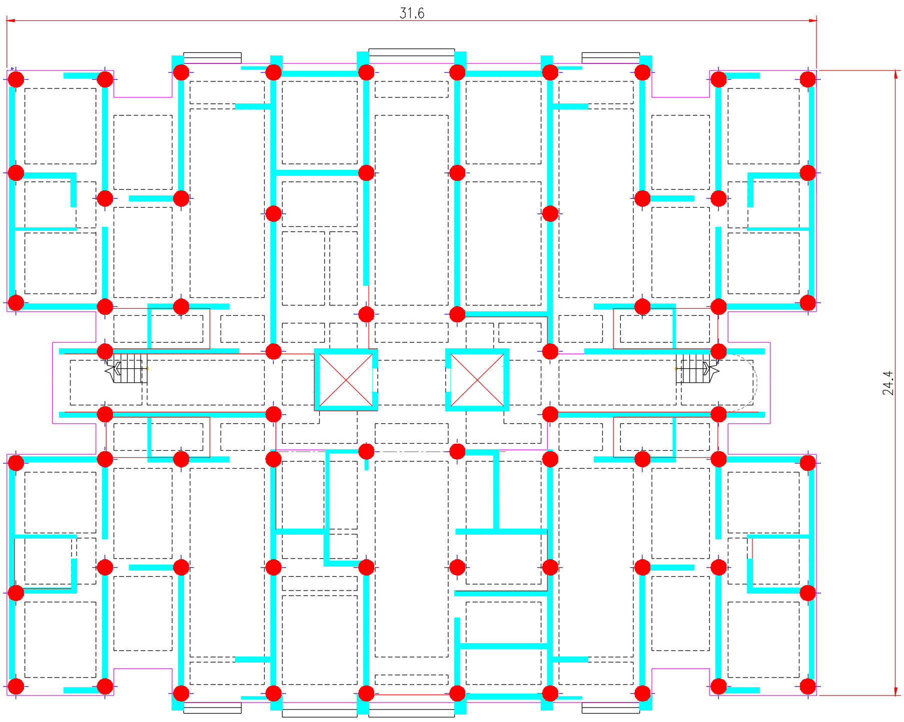

Figure 6 Plan of building Type A with isolators location

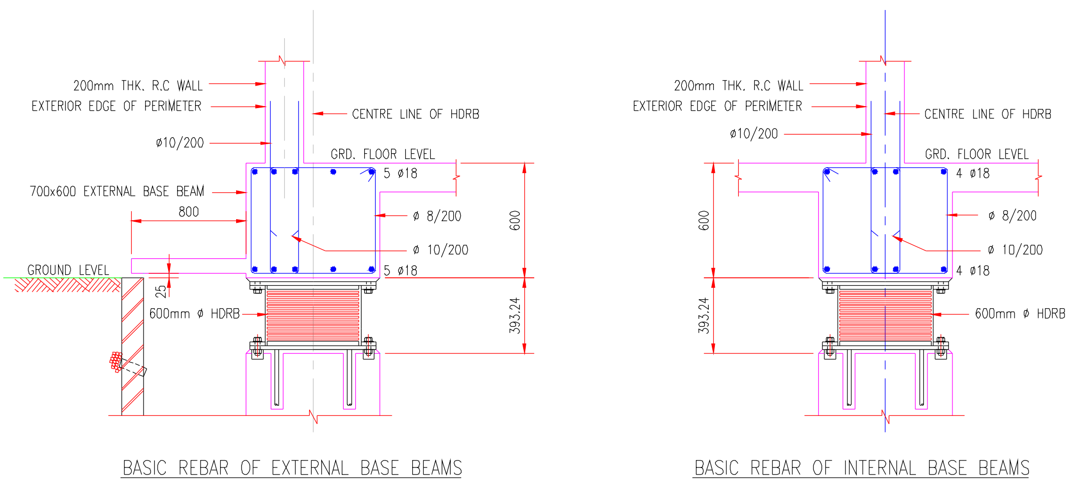

Figure 7 Details of the wall base

3.2 Isolation system and characteristics of isolated buildings

The isolation system is located at the ground level. The deepening of the foundation beams, required by the low soil strength, gives a space below the ground floor structures enabling access to the isolators for inspection and maintenance operations.

For all the buildings, a dual isolation system consisting of elastomeric isolators (High Damping Rubber Bearings, HDRB) and multidirectional pot bearings (Sliders) has been adopted. Table 2 shows the composition of the isolation system as well as the dynamic characteristics of the different types of buildings.

Table 2 Characteristics of the isolation systems and isolated periods

Block type	HDRB n°	HDRB diameter (mm)	Slider n°	Isolated period (s)
A	64	Φ 600	2	2.87
B main	34	Φ 500	26	2.77
B minor	22	Φ 500	11	2.71

4 ISOLATORS DESIGN & TESTING

The elastomeric isolators were designed according to a draft of the proposed CEN standard for Antiseismic Devices (CEN, 2006); the isolators satisfied all the requirements in that document. The following Table 3 gives the input parameters for the isolation system of the 12 storey “Type A” building obtained from the structural analysis, the design parameters of the isolators and the characteristics of the isolators as calculated from the design equations.

Table 3 Building “Type A” elastomeric isolators

Input parameters	
Maximum total horizontal design displacement	233 mm
Average non-seismic vertical load	1900 kN
Maximum vertical load including seismic	3500 kN
Minimum vertical load including seismic	-120 kN
Isolator design	
Overall diameter	600 mm
Overall height including bonded endplates	343 mm
Number of rubber layers	33
Design rubber shear strain (average over isolators)	105%
Rubber shear modulus	0.8 MPa
Nominal isolator characteristics	
Compressive stiffness	1500 kN/mm
Shear stiffness	1 kN/mm

The elastomeric isolators were manufactured by MIN Industries Sdn Bhd of Malaysia. Prototypes were produced and tested according to a protocol based on the draft standard (CEN, 2006). The tests, carried out on a biaxial bearing tester, gave the following results: compressive stiffness = 1100kN/mm; shear stiffness at design displacement = 0.93kN/mm; damping at design displacement = 13%. Tests were witnessed by Malaysian Rubber Board on behalf of Numeria.

A pre-prototype isolator under combined compression and shear is seen in Figure 8. The production isolators were also tested according to a protocol based on the draft standard (CEN, 2006). For all isolators, the compressive stiffness was measured, and a visual check made while the compression test load was applied. The shear stiffness and damping at the design displacement of the first 20 production isolators was measured; as all the 20 isolators passed, the proportion subsequently subjected to the shear test was lowered to 50%. In all 193 MIN isolators were manufactured and tested under the supervision of Numeria.

The developer later starting to source isolators from another manufacturer, and Numeria ceased to take responsibility for the testing and verification of the isolators.

Figure 8 Pre-prototype isolator under combined compression and shear. Displacement = 245mm, Vertical load = 1900kN

5 INSTALLATION ISSUES

The on-site installation of the devices is a crucial aspect of a base isolated building. Tolerances and procedures required during the installation are far from those normally observed in civil construction works, but they have to be strictly respected because the safety and the proper behavior of an isolated structure depends on the correct installation. Transportation, storage and installation procedures were defined that could be easily followed by inexperienced workers, guaranteeing, at the same time, rigorous respect of the specifications and simplicity. Particular attention was also devoted to the grouting as the environmental conditions, characterized by strong variations in temperature and humidity between seasons, might affect the process.

Figure 9 Left: isolators ready for installation and foundation rebar; right: level check of the counter-plate

Figure 10 Left: casting of stumps for isolators; right: laying down of the first isolator

6 FRAMED VARIANT OF THE STRUCTURAL SYSTEM

After successful completion of the design of the 12 storey building in the shear wall configuration, the authors proposed to the developer a structural scheme made only by beams and columns; this would enable more effective use of the benefits of the base isolation technique and thus result in improved performance and cost savings. The elimination of the shear walls implied a minor revision of the architectural layout, but allowed for a significant reduction of the construction costs due to the substitution of r/c walls with light-weight brick walls, and for the reduction of the structural masses and hence of the total weight of the building with consequently reduced foundation dimensions; the lower mass of the structure also enabled smaller isolators to be used. The target of the developer for a 25% cost saving was achieved with the framed configuration whose layout is reported in Figure 11.

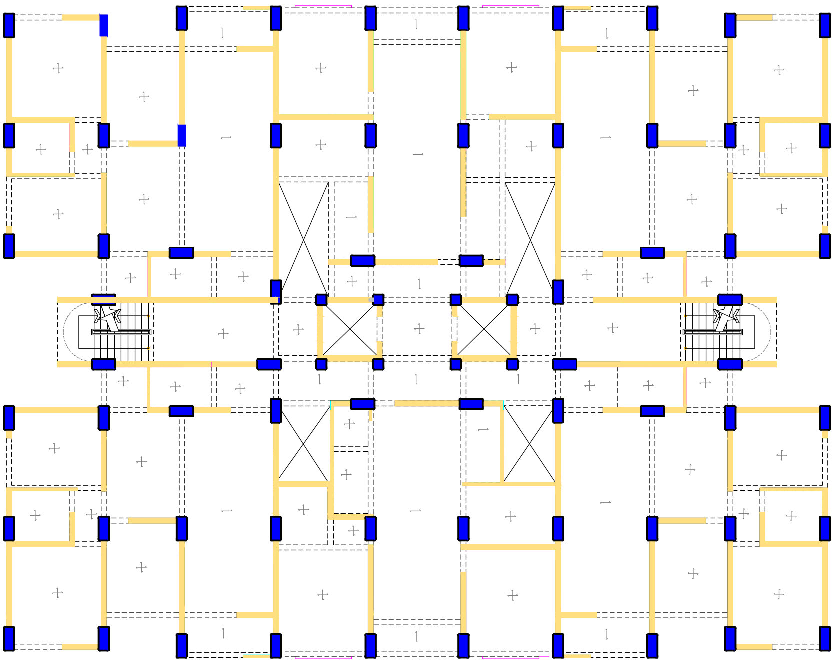

Figure 11 Columns location in the framed variant of building A

7 CONCLUSIONS

The structural designs presented confirm base isolation to be effective in enhancing the performance of ordinary residential apartment building, and that its use may add only a few percent of the total construction cost. The choice of a suitable structural type and configuration is important for obtaining a significant reduction of costs. In the example presented a cost-saving larger than 20% resulted from the use of a framed structure in place of a wall system. Great attention should be paid to ensuring proper building operations through: a) respect of the design procedures, b) application of the material specifications, and c) inspection of the on-site operations. This is especially important where there are generally poor skills and lack of quality control on-site. Some deficiencies in these aspects for the project described here have been observed by the authors, mainly concerning the foundation construction, the reinforcement detailing and the isolators' connections, and as a consequence they are no longer involved in the project and in particular with the implementation on site.

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