Plaza Rakyat Office Tower : Structural Systems and Design Concepts

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INTRODUCTION

At 382 metres in height, the Plaza Rakyat Office Tower will displace the Empire State Building in New York as the seventh tallest building in the world. The 77-storey tower in Kuala Lumpur, Malaysia will be, at time of completion, the tallest all-reinforced concrete building in the world and also one of the most slender with an overall aspect ration of over 8 to 1. The lateral load resisting system employed for the tower is predicated upon the generally benign wind and seismic environment in Kuala Lumpur and may be termed a core and indirect outrigger system. Three "outrigger" locations are arranged at various points along the height of the building with the bottom two outrigger locations corresponding to mechanical spaces. At these mechanical floor spaces, the core is linked to the exterior frame indirectly through a continuous, closed, reinforced concrete perimeter belt wall and the action of the floor diaphragms without vertical outrigger walls or trusses extending through the mechanical space. These belt walls, while not being fully as effective as a conventional direct outrigger wall connecting the core to the exterior frame, are sufficient in this case to provide the necessary strength and stiffness against overturning due to lateral loads. One advantage of the belt wall / core interacting system is the elimination of the outrigger wall encumbrances to plumbing and mechanical equipment layouts in these spaces. More importantly, the prediction of stresses and the design of conventional outrigger elements in reinforced concrete high-rise building is rendered difficult and somewhat uncertain due to the differential inelastic creep and shrinkage deformations of the vertical core walls and exterior columns. The belt wall / core interaction system does not include a direct connection from interior to exterior and therefore must only be proportioned for forces arising from vertical load redistribution along the exterior. The creep and shrinkage effects remain extremely important, however, in terms of serviceability issues such as floor levelness and exterior wall concerns. This article summarizes the primary structural engineering aspects of the tower design including the design for wind and gravity as well as vertical creep and shrinkage analysis and compensation.

GRAVITY LOAD RESISTING SYSTEMS

The structure for the 77-storey Plaza Rakyat office tower is formulated based on the desire for economy through simplicity and repetition. The structure is framed entirely in reinforced concrete due primary to the predominant use of the material over structural steel in Malaysia. Typical low-rise and high-rise floor framing plans are shown in <Figure 1>. Gravity loads are collected on the exterior perimeter by large rectangular columns spaced 9.0m on center. These columns have a constant face dimension parallel to the plane of the exterior wall of 1200mm and vary along the height of the building from 2700mm at the base to 1500mm at the Level 51 transfer. Column size transitions are made only on the inside face of the column only in order to simplify formwork and detailing with respect to the exterior wall. The column sizes above Level 53 are reduced to 800mm square in order to provide less encumbrance to sightlines for the upper level office spaces. The concrete strengths utilized are quite low (C50 and C40 grades) for a building of this height in order to avoid the introduction of foreign concrete technologies. The design for the exterior columns was controlled primarily by considerations of strength under gravity loads alone. The remainder of the gravity load is supported by the rectangular core which is organized around the central elevator, stair and services areas. Vertical walls on the perimeter of the core vary in thickness from 850mm at the base to 450mm at the roof. Internal walls in each direction of constant 300mm thickness frame the various elevator banks in the core. It is anticipated that the concrete core walls will be constructed some 5 to 6 stories above that of the floor and exterior column construction.

Between Levels 51 and 53, the buildings exterior steps inward some 3.0 meters. All exterior columns are transferred through two-storey high reinforced concrete shear panels which avoid the necessity of deep transfer girders at Level 51. The transfer is accomplished through the strength and rigidity of the floor slabs in compression at Level 53 and tension at Level 51. There is no net horizontal load on the building as the loads from the two sides of the building oppose each other.

The floor framing system was chosen based on value-engineering analysis between the architects, engineers, and Daewoo Construc- tion to determine the system which would produce the least overall building cost-not necessarily the least structural cost. For this reason; a wide, shallow beam scheme was conceived with the beam profile 1200mm wide to match the width of the exterior column (an economical arrangement for the formwork system) by 500mm deep. These beams are conventionally reinforced without prestressing and are spaced 4.5m on center spanning between the exterior frame and the core wall. A continuous 600mm wide by 800mm deep spandrel beam connects the exterior columns on the building perimeter and also supports every other floor beam on the 4.5m module as well as the architectural curtain wall. The floor beams are integrally connected th the core walls through a pocket detail boxed-out in the wall construction. While not as structurally efficient as a deeper beam section, the shallow beams serve to reduce the typical storey height to 3.9m resulting in economies in the exterior curtain wall, elevatoring, interior partitioning, and vertical plumbing and mechanical riser costs. In addition, the wide beams shorten the effective one-way slab span transversely between the beams resulting in a typical office floor slab thickness of 120mm which also meets the applicable 1.5-hour fire resistance requirement between floors. On mechanical floors due to heavier imposed loads, thicker slabs are specified with the corresponding beam depths adjusted such that the stem(portion of the beam below the slab soffit) remains unchanged. This allows for an extremely simple formwork system which may be repeatedly reused. Above the Level 51 transfer zone, although the beam spans are significantly shorter, the same beam profile is again used as a logical extension of the system below.

The tower is supported below basement Level

B6 on a pile supported 3.5m thick reinforced concrete mat foundation. All piles are 900mm diameter slurry piles varying in length from 22m on the exterior to 32m in the core area into the underlying Kenny Hill formation strata.

VERTICAL DEFORMATION ANALYSIS (ELASTIC, CREEP AND SHRINK AGE EFFECTS)

The estimation of vertical deformation including the effects of inelastic concrete creep and shrinkage is one of the most important concerns in the design and construction of tall reinforced concrete and composite (mixed) buildings. For the Plaza Rakyat Project, SOM developed a state-of-the-art computer analysis program to determine the magnitude of the vertical deformations of the tower columns and core walls. This program was used to develop initial compensation values for the construction based on an assumed construction schedule and material coefficients. While computer analysis and simulation of the column shortening process is critical, concrete material laboratory analysis and testing for creep and shrinkage characteristics is equally important. To this end, a concrete creep and shrinkage testing program was initiated at the local University of Malaysia to provide material coefficients based on the mix designs to be utilized on the project. Based on the results of the material testing and the assumed construction sequence, compensation values(cambers) for the construction of the core wall and for the differential deformation between the core and exterior were generated to be used during construction. A plan is currently being to adjust the vertical compensation design based on survey data from the actual construction.

LATERAL LOAD RESISTING SYSTEMS

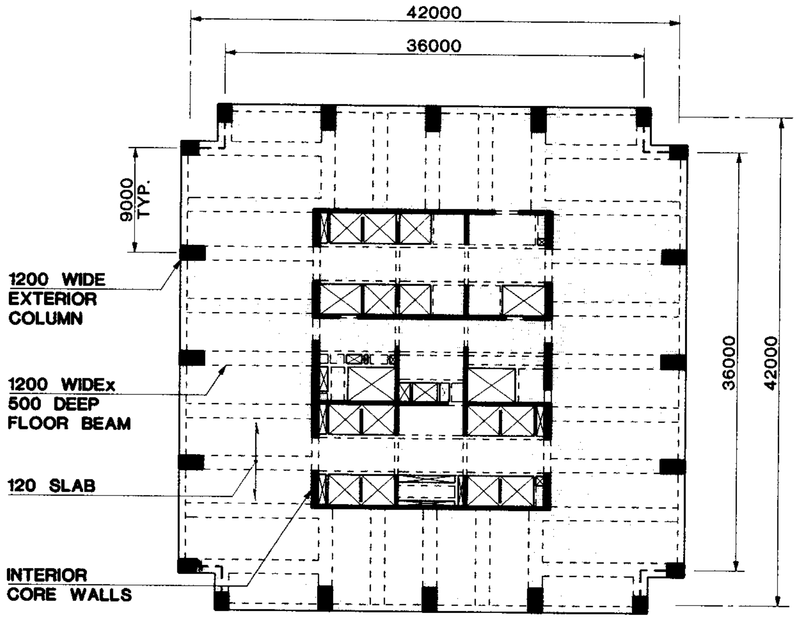
The lateral load resisting system components are indicated in <Figure 2>. The system components are the concrete core walls and coupling beams, the exterior beam/column frame, and the two storey belt and outrigger walls located at levels 28, 51 and 73. The system was developed based on the extremely light wind loading environment inherent for Kuala Lumpur. In fact, must of the lateral load resisting system design was controlled by consideration of strength rather than stiffness; a situation quite unusual for a building of this height which is often be controlled by the design for occupant motion perception. <Figure 3> shows a hypothetical comparison of building accelerations for various return periods for the Office Tower structure in the Kuala Lumpur, Chicago and Hong Kong wind environments. As can be seen, only in the Kuala Lumpur location is this type of structure adequate to resist the wind loads in terms of motion perception. For the purposes of comparison, accelerations at a standard 10-year return period in Chicago or Hong Kong would be more than 5 or 10 times those in Kuala Lumpur and would be unacceptably high which would require modification to the structural system.

Initial schemes for lateral load resistance included outrigger walls which passed through the mechanical spaces at Levels 28 and 51 linking the core and exterior frame. Based on the results of wind-tunnel testing it was determined for the Kuala Lumpur wind climate that these outrigger walls could be removed in favor of perimeter "belt" walls along the exterior of the building only. The belt wall system is termed a partial or indirect outrigger system as axial forces in the exterior columns are induced under lateral wind loading through the interconnecting action of the floor diaphragms between the core and the exterior at the mechanical floors. See <Figure 4>. The advantage of the belt wall / core interacting system over a more conventional direct outrigger wall system are twofold. First, the belt walls on the perimeter open up the mechanical floors allowing more freedom in placing mechanical and plumbing equipment in the plant space. Second, and more importantly, the belt walls do not constitute a direct link between the core and the exterior frame as does a conventional outrigger system. One of the most difficult problems for such a direct outrigger beam or wall system is the fact that due to the immense stiffness of the outrigger, there is a tendency for the outrigger to "support" the exterior frame from the core in a cantilever mode resulting in high gravity transfer loads in the outrigger elements. For a structural steel system, this phenomenon can be designed into the structure as the stiffness and loads are quite well defined. For a reinforced concrete outrigger wall system, however, the gravity loads supported through the outrigger link are much more difficult to quantify due to inelastic (creep) redistributions. In this way, the belt wall / core interacting system is more reliable as the walls must only be capable of distributing gravity loads among the exterior columns which normally have relatively equal stress levels thus producing little gravity transfer loads in the belt walls.

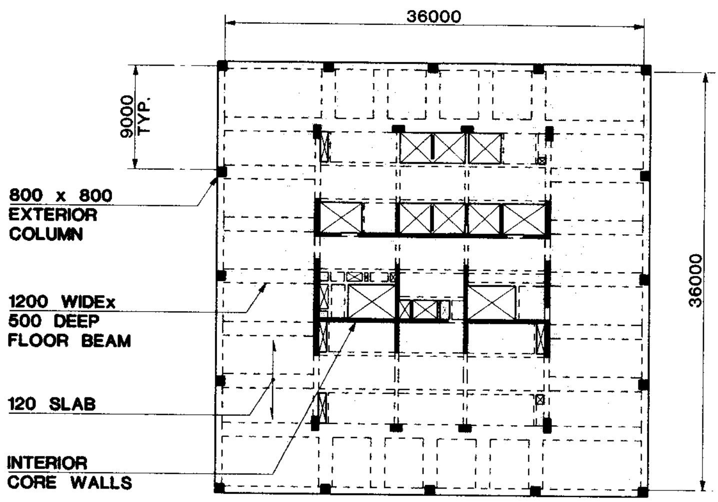
The fundamental behavior of the belt walls under lateral load is also shown in <Figure 4>. The belt walls provide an extremely stiff two-storey link which tends to pull back the overall deflected shape of the building. In addition, direct outrigger walls from the core to the exterior at Level 73-75 provide a 10～15% increase in lateral stiffness to the building.

CONCLUSION

The structural engineering design for the Plaza Rakyat Office Tower continues a long tradition of systems development for tall buildings which attempts to refine and improve the efficiency and economy of the structure. A powerful new system, the belt wall / core interacting system has been introduced and is applicable to very tall buildings in moderate to wind climates and to buildings in the mid-height range in moderate to high wind climates. By combining material and construction efficiency, an economical structural system meeting all of the engineering requirements for strength and stiffness may be realized while also responding to the unique architectural requirements of the program and budgetary constraints.

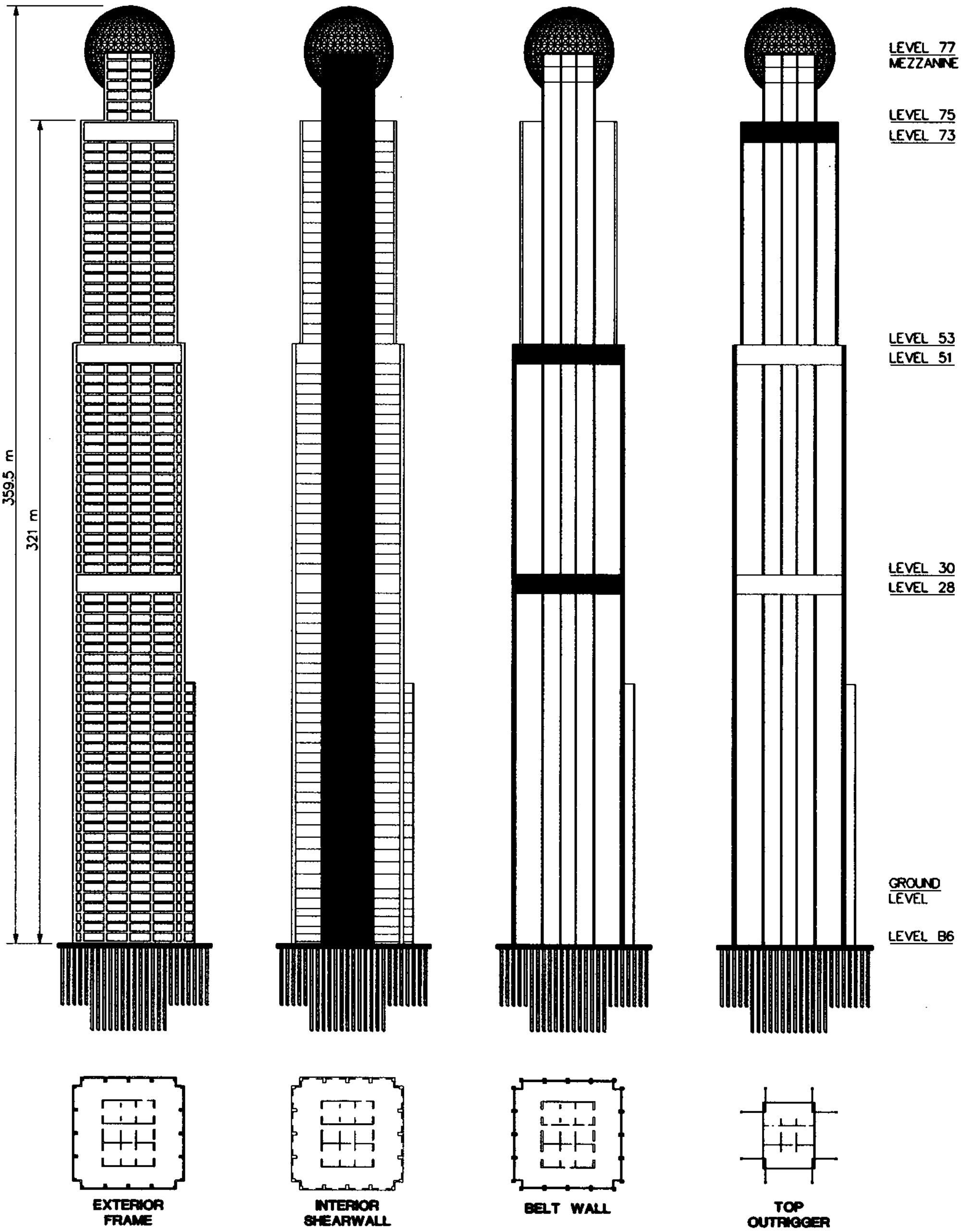


TYPICAL LOWRISE FRAMING PLAN

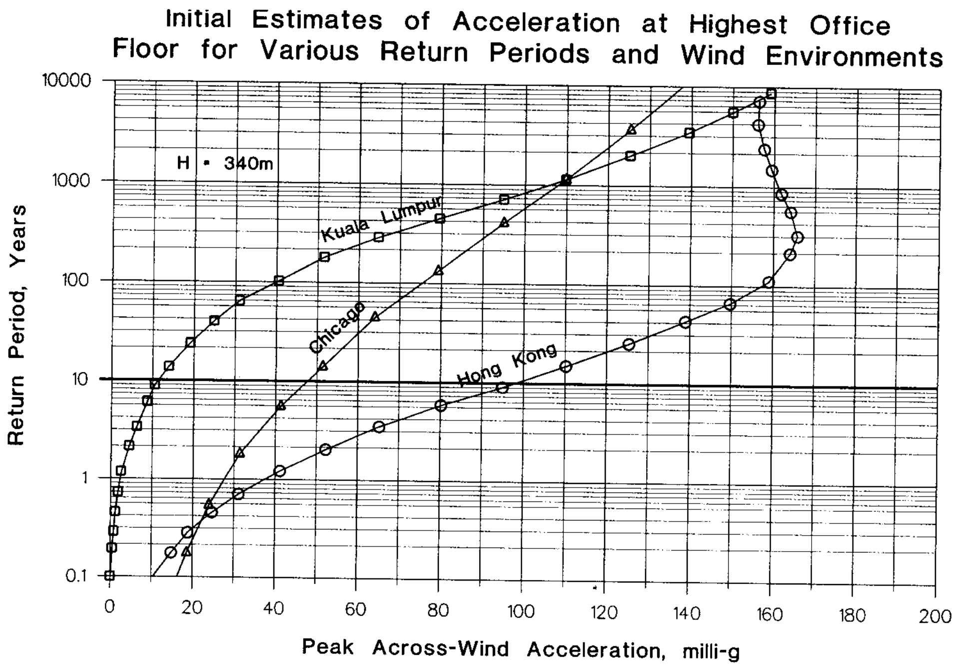


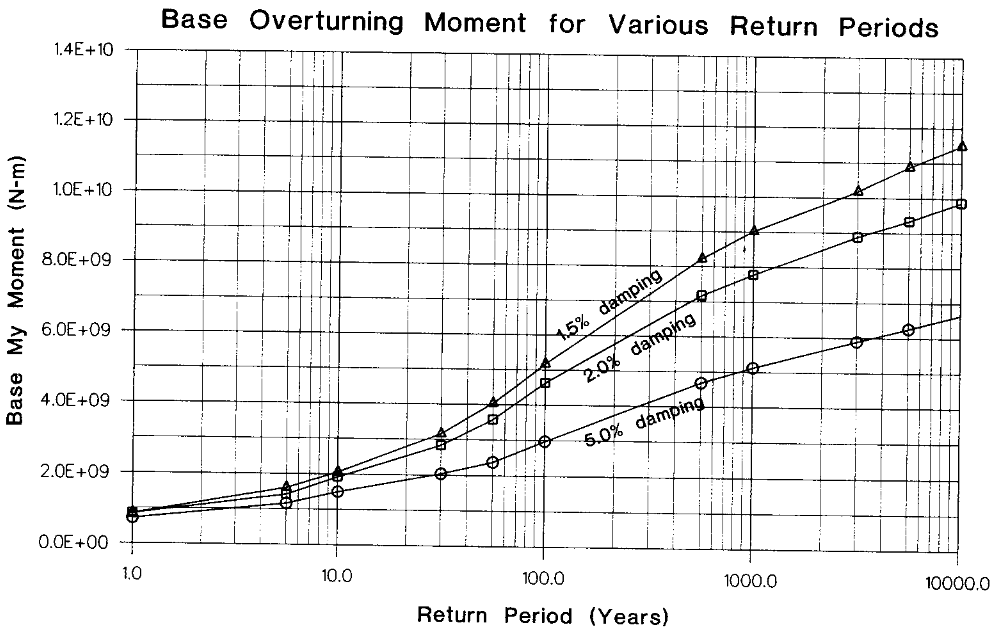
TYPICAL HIGHRISE FRAMING PLAN

<Figure 1> OFFICE TOWER GRAVITY LOAD RESISTING SYSTEMS

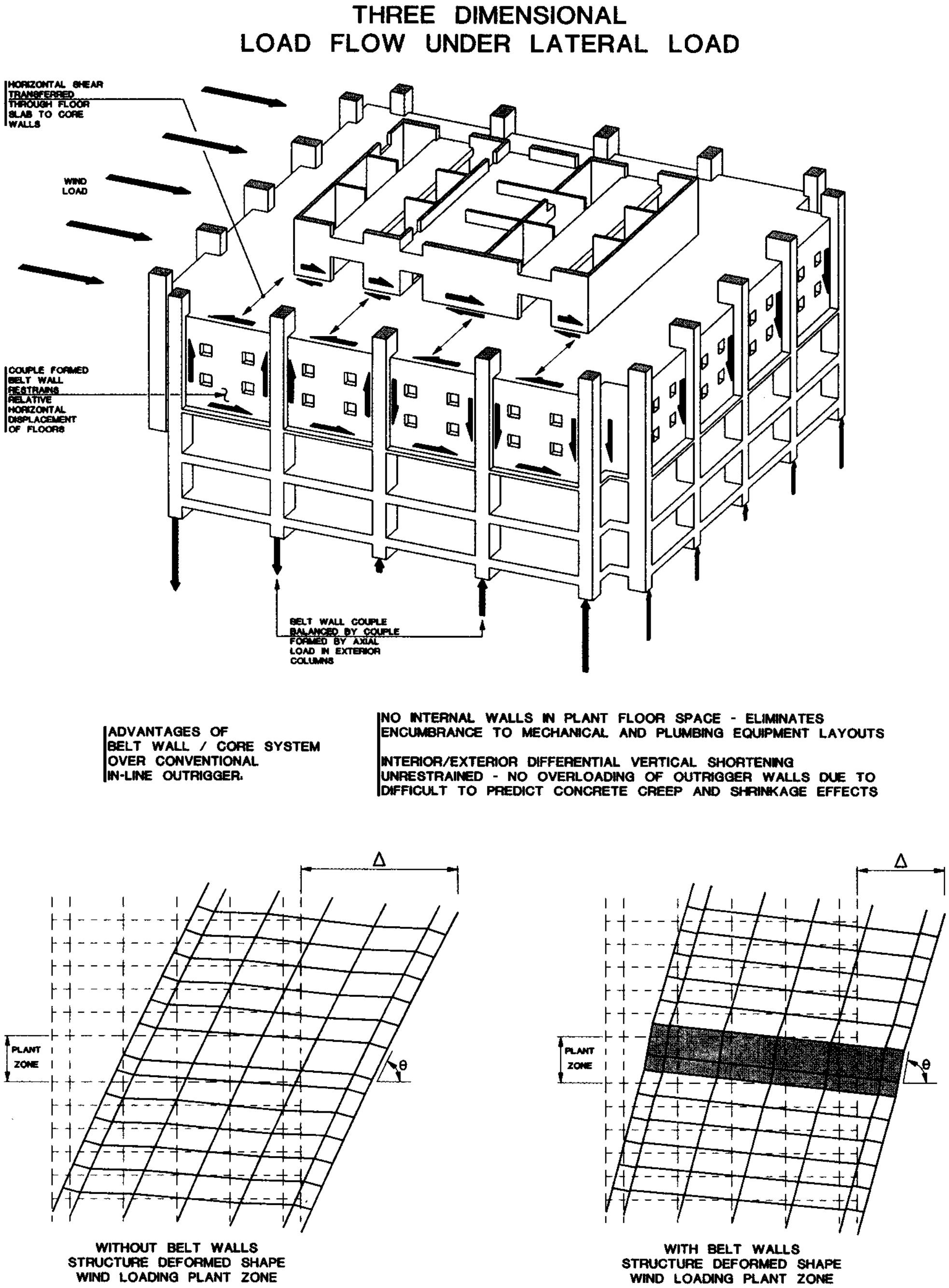


<Figure 2> LATERAL LOAD RESISTING SYSTEM COMPONENTS





<Figure 3> WIND ENGINEERING



<Figure 4> BELT/CORE INTERACTING SYSTEM CONCEPT