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Performance-based Seismic Design of an Irregular Tall Building — A Case Study

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ABSTRACT

The structural design of a 50-story tall reinforced concrete residential building, which was planned to be constructed in Istanbul and given up afterwards by the investor, has been completed in accordance with the draft version of Seismic Design Code for Tall Buildings in Istanbul that adopts performance-based seismic design as the basic approach as Tall Buildings Initiative Guidelines do. The seismic design of the building has formed the main part of the structural design process due to high seismicity of the proposed location and the extremely irregular floor plan not conforming to usual tall building structures. The building consists of two individual buildings linked through stronger link slabs at top 13 stories whereas relatively weak slabs at lower stories. The building has been designed for design basis earthquake by elastic response spectrum analysis and its seismic performance has been checked for maximum considered earthquake by nonlinear time history analyses carried out using PERFORM-3D.

1. Introduction

Application of performance-based seismic design (PBSD) to tall buildings is relatively new although its history goes back to 1980s. With the issue of PBSD recommendations such as Recommendations for the Seismic Design of High-rise Buildings by Council on Tall Buildings and Urban Habitat [7], An Alternative Procedure for Seismic Analysis and Design of Tall Buildings Located in the Los Angeles Region by Los Angeles Tall Buildings Structural Design Council [16], Requirements and Guidelines for the Seismic Design and Review of New Tall Buildings using Non-Prescriptive Seismic-Design Procedures by Structural Engineers Association of Northern California [26], and finally Guidelines for Performance-Based Seismic Design of Tall Buildings by Tall Buildings Initiative Guidelines Working Group [27], many buildings especially located in high seismicity regions have been designed using the PBSD method around the world [3,15,32]. As expressed in these documents, PBSD has many advantages over traditional prescriptive code-based design methods whose regulations are not fully suitable for tall buildings for their unique structural behavior. Traditional design codes, briefly, a) are basically prepared to regulate the design of low and medium rise buildings whose first translational mode is taken into account in seismic analysis; b) have application limitations with regard to building height; c) impose rigid rules on the analysis and structural system; and d) prescribe elastic analysis with the seismic force reduction factor which was widely investigated by various researchers [9,17,20,22,29,31] in order to account for the inelastic behavior of the buildings under major earthquakes, although it cannot be theoretically defined especially for tall buildings due to their unique structural behavior. Unlike these drawbacks of prescriptive code-based design, PBSD makes it possible to more realistically obtain displacements and accelerations of stories, effects of higher modes and redistribution of shear forces of tall buildings in an inelastic behavior range [14,18].

Few codes in the world have regulatory requirements towards PBSD of tall buildings. Seismic Design Code for Tall Buildings in Istanbul [25] was proposed in 2008; however it hasn't been put into implementation yet. SDCTBI adopts the PBSD method and has provisions like those of previously mentioned documents. Design objectives in SDCTBI are briefly stated as a) negligible damage and immediate occupancy performance level under earthquake with 50% probability of exceedance in 50 years (return period of 72 years) entitled D1 and service level earthquake (SLE); b) controllable damage and life safety performance level under earthquake with 10% probability of exceedance in 50 years (return period of 475 years) entitled D2 and design basis earthquake (DBE); and c) extensive damage and collapse prevention performance level under earthquake with 2% probability of exceedance in 50 years (return period of 2475 years) entitled D3 and maximum considered earthquake (MCE).

Various studies were conducted to investigate and advance the application of PBSD to tall buildings especially in the last 10 years. Case studies [13,18,30] conducted by Pacific Earthquake Engineering Research Center, University of California, Berkeley (PEER) aiming at

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defining the seismic performance of tall buildings designed by alternative means have been among the most important works in this regard so far.

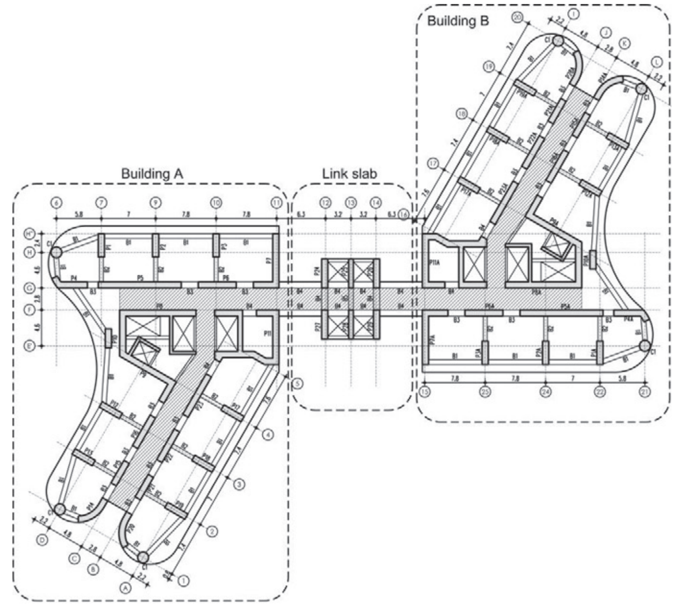
In this paper, the structural design procedure of the proposed building whose first version was presented by Özuygur [21] completed in accordance with the regulations of SDCTBI along with the recommendations of other guidelines is presented. The building has been designed for DBE by elastic response spectrum analysis and its performance has been checked for MCE by nonlinear time history analyses, and brief analysis results and observations have been summarized.

2. Structural design of the building by linear analysis

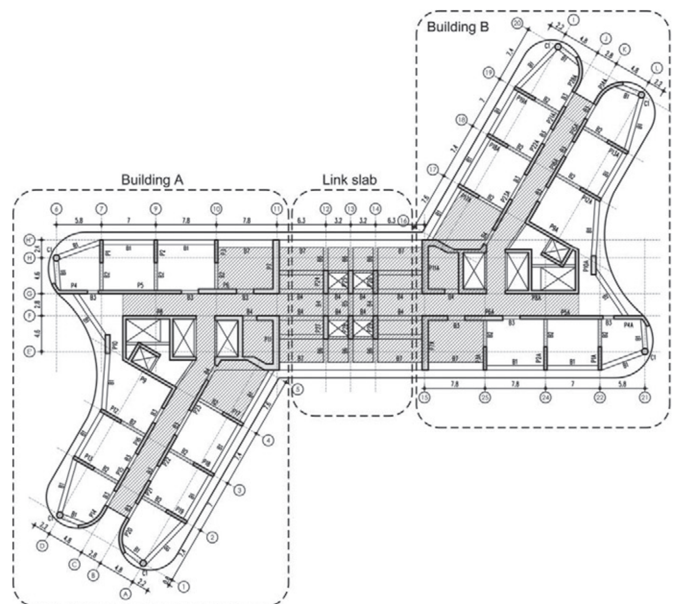
2.1. The structural system

The residential building whose architectural render is given in Fig. 1 and which is planned to be constructed in the Bomonti district of Istanbul has 50 stories above and two additional stories below grade. The total height of the building from the foundation level is 198 m with 3.8-m story height above grade and 4-m story height below grade. The building has an extremely irregular structural floor plan as shown in Fig. 2 imposed by rigid architectural requirements which is not usually suitable for tall building structures. The structural floor plan is antimetric at axis 13. The vertical load bearing system of the building consists of concrete slabs sitting on beams supported by shear walls and columns. The lateral load carrying system of the building consists of shear walls with coupling beams distributed in the floor plan as required by architectural needs. Dimensions of the structural

Fig. 1. Architectural render of the building by Tago Architects.



(a) Typical floor plan below level 183.30 m.



(b) Typical floor plan above level 187.10 m.

Fig. 2. Typical floor plan.

elements of lower stories are summarized in Table 1. General slab thickness is selected as 0.16 m by iterative analysis of vibration and long-term deflection under sustained loads. The slab of the corridor area between shear walls is selected as 0.3 m in order to increase the lateral stiffness of the building. The structure can be considered as two individual buildings (Building A and Building B) linked through a weak corridor slab (link slab) at most of the stories (Fig. 2a) and a fully continuous floor slab (link slab) at top 13 stories (Fig. 2b). The slab thickness of the link area and adjacent spans at top 13 stories is selected as 0.3 m considering in-plane forces of the slab caused by different dynamic behaviors of the buildings under seismic forces. Thicknesses of the shear walls are 0.8 m at lower stories and gradually reduced to 0.4 m at top stories. The thickness of the shear walls at axis 11 and axis 15 is 0.8 m all over