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MCEER Hospital Demonstration Project

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Summary

The MCEER Demonstration Hospital Project is intended to facilitate integration of MCEER research on characterization and retrofit of structural and nonstructural components and systems in mission-critical structures such as hospitals. The baseline hospital was constructed in the mid 1970's and is located in Southern California. This paper presents structural engineering information on three medical facilities: the original facility and two derivative facilities, one representing 1960's West Coast construction and one representing 1970's East Coast construction. Construction data were obtained for the design of the derivative facilities and the three building models were analyzed by nonlinear static analysis.

Introduction

The MCEER Demonstration Hospital Project is intended to facilitate integration of MCEER research on characterization and retrofit of structural and nonstructural components and systems in mission-critical structures such as hospitals. A complete description of this project can be found on the world wide web at *http://civil.eng.buffalo.edu/hospital/*.

The baseline hospital was constructed in the mid 1970's and is located in Southern California. This hospital was most likely designed to meet the seismic requirements of the 1976 Uniform Building Code. The mathematical model of this structure was simplified by assuming a rectangular plan and by replacing the penthouse at the top of the actual facility and the vertical shafts for mechanical and vertical transportation systems by typical floor framing. The resulting building model is termed West Coast 1970's (WC70).

The Uniform Building Code has been used for seismic design in California from the late 1920's until the introduction of the 2000 International Building Code in 2001. The Uniform Building Code was substantially revised in the 1960's, and many of these revisions were proposed by expert earthquake engineers in California. Limits on allowable displacements in buildings were introduced in the 1976 edition. These limits led to substantial increases in the required lateral stiffness of flexible buildings such as steel moment frames. Consequently, the lateral strength of moment-frame buildings increased. As such, the stiffness and strength of 1970's moment-frame construction are significantly greater than those of 1960's construction. In order to contribute to the development of retrofit strategies for structural components and systems typical of weak and flexible buildings similar to those constructed on the West Coast in the early to mid 1960's, a framing system that complies with the gravity-load and seismic requirements of the 1964 Uniform Building Code was developed. This framing system was designed for the same gravity loads considered in the design of the baseline facility. The resulting model is termed West Coast 1960's (WC60).

Medical facilities on the West Coast have been designed for earthquake effects for more than 60 years. Such effects were not considered in the design of East Coast medical facilities until the 1990's. Consequently, a large number of medical facilities on the East Coast have minimal resistance to earthquake effects. In order to facilitate the preparation of retrofit strategies for a typical (vulnerable) 1970's East Coast medical facility, a second derivative framing system was developed. Structural members of this model were sized according to the requirements of the 1970 Building Code of New York City. Since this code did not include seismic requirements, framing systems complying with the Code were designed for gravity and wind loads only. The framing system developed for this project was designed for the same gravity loads considered for models WC70 and WC60. The resulting model is termed East Coast 1970 (EC70).

Description of the Existing Facility

The existing facility, modified as described in the introduction, is a 4-story steel frame building whose plan dimensions are equal to 275 ft in the east-west direction and 56.5 ft in the north-south direction. The height of the building, from grade level to the roof, is equal to 51 ft. A plan view of the building showing the grid lines in the NS and EW directions can be seen in Figure 1.

The floor framing consists of 5.5" thick concrete slabs on metal decking that span east-west to floor beams. These beams span north-south to steel girders, which in turn span east-west to steel columns. The gravity load resisting columns are supported on piled foundations. The lateral force resisting system consists of four moment-resisting frames in the north-south direction and two perimeter moment-resisting frames in the east-west direction. The three-bay north-south moment frames are located on Lines B, F, J, and N (Figure 1). The east-west moment frames are located on Lines 2 and 5. The moment frames are constructed with ASTM A572 and A588 Grade 50 steel. ASTM A36 steel was used for the remaining steel beams, girders, and columns. The foundation system beneath the moment-frames columns consists of 54" deep grade beams spanning to piles located on Lines 2, 5, B, F, J and N. Piles have a 12"x12" square cross-section and are typically 50 ft long. Piles are embedded 6" at the bottom of the pile cap. Pile caps have typically a 66"x66" square cross-section and are 60" deep. Pile caps are reinforced with bottom rebars only. The typical pile cap reinforcement consists of #10 bars at 12" on center, each way.

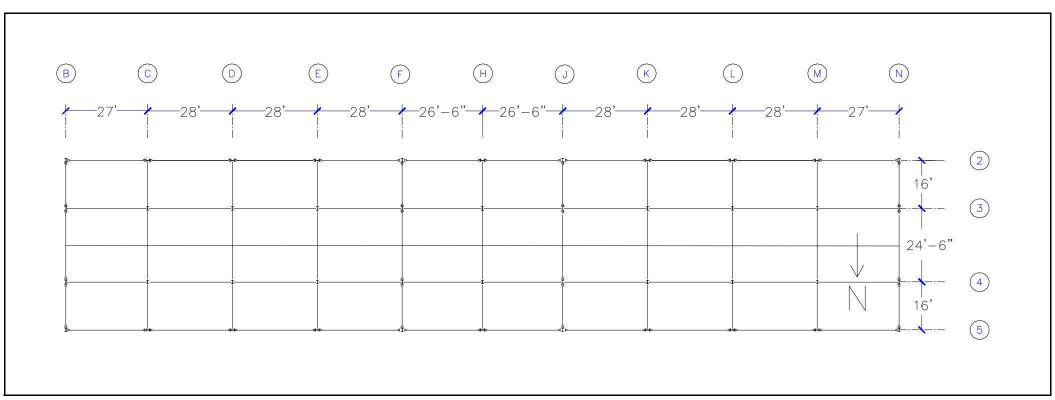

Figure 1. Plan view of the existing facility

Analysis and Design of Building WC70

The computer program SAP 2000 was used to model and analyze the existing facility (WC70). Centerline dimensions were used to define the lengths of the beams and columns; rigid end offsets were not considered. Only frames 2 & 5, B & N and F & J were modeled with rigid beam-column connections. All other beam-column connections were assumed pinned.

Reactive weights were calculated for each floor and story of the building. Calculations were based on a review of architectural and structural drawings of the building. Typical floor and roof loads are equal to 120 psf. The exterior wall was calculated to weigh 17.5 psf. Live loads were assumed equal to 40 psf for the typical floors and 20 psf for the roof. Live load reductions were considered when checking structural members.

Lateral (earthquake) forces were established as follows. The design base shear V was calculated as:

$$V = Z\,I\,K\,C\,S\,W \tag{1}$$

where Z is a seismic zone factor (= 1), I is an importance factor (= 1.5 for a hospital), K is a site base numerical coefficient (= 0.67 for a moment-resisting frame), S is a soil factor (= 1.5 for default soil condition), W is the reactive weight (= 9,800 kips for WC70), and CS_{max} = 0.14. The resulting design base shear (at the allowable stress level) is then equal to 1374 kips in both principal directions. Base shear V was distributed over the height of the building using the following equation from the 1976 Uniform Building Code:

$$F_i = \frac{w_i\,h_i}{\sum_{j=1}^{n} w_j h_j} V \tag{2}$$

where F_i is the design lateral force at level i, w_j is the reactive weight at level j, and h_j is the height of level j above grade.

Components were checked for the following load combinations required by the 1976 Uniform Building Code:

$$D + L \tag{3}$$

$$D + L + E \tag{4}$$

where D, L, and E are dead, live, and earthquake loads, respectively. A one-third increase in allowable stresses was considered when checking components under earthquake effects.

Analysis and Design of Building WC60

The framing system of the 1960's West Coast version of WC70 was established by modifying the size of beams and columns in moment-resisting frames (Lines 2, 5, B, F, J, and N) in such a way that they comply with the minimum requirements of the 1964 Uniform Building Code. New sizes were established in three steps as follows:

1. Beams and columns in moment-resisting frames were sized to resist gravity-load effects only.

2. Lateral (earthquake) loads were calculated per the 1964 UBC and imposed on the building frame.

3. The sizes of the beams and columns in the moment-resisting frames were increased from those calculated in step 1 as required to resist the forces induced by the load combinations of the 1964 UBC.

Lateral (earthquake) forces were established using the 1964 UBC as follows. The design base shear V was calculated as:

$$V = Z\,K\,C\,W = 0.045\,W \tag{5}$$

where Z is a seismic zone factor (= 1.0 for Zone 3 [Los Angeles]), K is a structural system factor (= 0.67 for moment resisting frame), W is the reactive weight (= 9,300 kips for WC60), and $C = 0.05 / \sqrt[3]{T} = 0.068$ (T = 0.40 sec) represents the spectral shape. The resulting design base shear (at the allowable stress level) is equal to 423 kips in both principal directions. Base shear V was distributed over the height of the building using Eq. 2, which is also included in the 1964 Uniform Building Code. Components were selected and checked for the load combinations specified in Eqs. 3 and 4, which also apply for the 1964 Uniform Building Code. Again, a one-third increase in allowable stresses was considered when checking components under earthquake effects. Grade A36 steel was assumed for all members of model WC60.

Analysis and Design of Building EC70

The framing system for the 1970's East Coast version of WC70 was established by modifying the size of beams and columns in moment-resisting frames (Lines 2, 5, B, N, F, and J) in such a way that they comply with the minimum requirements of the 1970 Building Code of New York City. New sizes were established in three steps as follows:

1. Beams and columns in moment-resisting frames were sized to resist gravity-load effects only.

2. Lateral (wind) loads were calculated per the 1970 BCNY and imposed on the building frame.

3. The size of beams and columns in moment-resisting frames were increased from those calculated in step 1 as required to resist the forces induced by the load combinations of the 1970 BCNY.

Following the 1970 BCNY, the structural frame was designed for a lateral (horizontal) wind pressure equal to 20 psf on the vertical projected surface. Components were selected and checked for the following load combinations per the requirements of the 1970 Building Code of New York:

$$D + L \tag{6}$$

$$0.75\,(D + L + W) \tag{7}$$

where D, L, and W are dead, live, and wind loads, respectively. Grade A36 steel was assumed for all members in model EC70. Live load reduction was considered for the design of beams and columns under gravity loads.

Summary of Results

Maximum horizontal story drifts (expressed as a decimal fraction of the story height) under the action of code lateral forces are summarized in Table 1. Modal properties of the three mathematical models are summarized in Table 2. Base shear vs. lateral displacement ("pushover") curves obtained from nonlinear static analysis, along with estimates of the lateral strength of the buildings obtained from plastic analysis, are presented in Figure 2.

Table 1. Interstory drifts under lateral loads

Story	WC70	WC60	EC70
1	0.0024 h_1	0.0033 h_1	0.0030 h_1
2	0.0033 h_2	0.0046 h_2	0.0040 h_2
3	0.0031 h_3	0.0049 h_3	0.0065 h_3
4	0.0021 h_4	0.0035 h_4	0.0060 h_4

Table 2. Results of eigenvalue analysis

Building model	Mode	Period	Frequency	Participating mass ratio (EW direction)	Participating mass ratio (NS direction)
WC70	1	0.87 sec	1.15 Hz	82.72%	0.00%
	2	0.82 sec	1.22 Hz	82.72%	82.87%
WC60	1	1.86 sec	0.54 Hz	0.00%	80.43%
	2	1.76 sec	0.57 Hz	83.09%	80.43%
EC70	1	2.50 sec	0.4 Hz	0.00%	81.23%
	3	2.06 sec	0.46 Hz	85.45%	81.23%

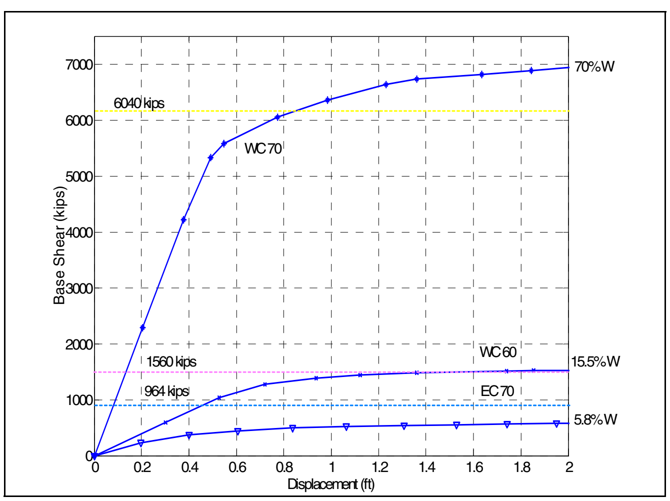

Figure 2. Pushover curves for the three building models

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