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FORCED VIBRATION TEST OF A FOUR-STORY REINFORCED CONCRETE BUILDING WITH TWO BASEMENT FLOORS

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ABSTRACT: Forced vibration testing provides the most direct means of determining the structural system dynamic properties of existing buildings. Structural vibrations due to the harmonic excitation of a vibration generator, which is typically mounted on one of the top floors, are recorded and acceleration-frequency responses are obtained upon digital signal processing of these records. Dynamic properties are then determined by well-established methods in the structural dynamics area. This paper presents the recent forced vibration test of a four-story reinforced concrete school building, which is the first permanently instrumented building in Turkey and nearby the North Anatolian Fault. It was originally a six-story building before its top two floors shaved off during its seismic strengthening by addition of shear walls into its structural system. During its forced vibration test, a dense network of 18 uniaxial accelerometers is used for monitoring the structural responses. Natural vibration periods, modal damping capacities, and natural vibration mode shapes of the building that are identified from its forced vibration test will later be used in calibrating its finite element structural model as part of a European Union project, which ultimately aims to assess the seismic fragility of instrumented buildings in earthquake prone areas of Europe.

1. Introduction

Structural system dynamic properties control the responses of buildings to earthquake, wind, blast, and other dynamic excitations. In-situ dynamic testing of buildings is especially important in determining their natural vibration modes — periods (and frequencies), damping capacities, and mode shapes. Forced vibration testing, which does not require sophisticated system identification algorithms, unlike ambient vibration testing and seismic monitoring, provides the most direct means of determining the dynamic properties (Celik et al., 2015). This paper presents the forced vibration test of the first instrumented building in Turkey, which is nearby the North Anatolian Fault (Gulkan et al., 1994). Identified dynamic properties will later be used to validate and calibrate the-state-of-the-art finite element structural model of the building.

2. Building Description

Belkis Sabanci Dormitory is a four-story reinforced concrete building with two basement floors, in close proximity to the surface rupture that occurred during the 1944 M_w 7.4 Gerede earthquake in Bolu, Turkey, which was permanently instrumented to record the structural responses in the case of earthquakes that may occur along the nearby North Anatolian Fault (Gulkan et al., 1994). Figure 1 shows the building from its southwest corner. It was originally a six-story building when its construction was completed in 1988. Its structural system consisted of moment resisting frames along both the North-South (N-S) and East-West (E-W) directions, with 4.2 m long shear walls along the N-S direction on each side of the staircase (Fig. 2), which complied with the 1975 Turkish Earthquake Code (Ministry of Public Works and Settlement, 1975). Its top two floors were later shaved off during its strengthening with cast-in-place reinforced concrete infill walls along both directions as shown in Fig. 2. The total height of the building up to the roof is 22.4 m including the basements. The story height is 3.6 m. Concrete grade is C25; TS 500 (Turkish Standards Institute, 2000) defines its characteristic compressive strength as 25 MPa. The building has spread footings and rests on a soil medium consisting of dense sand and clay.

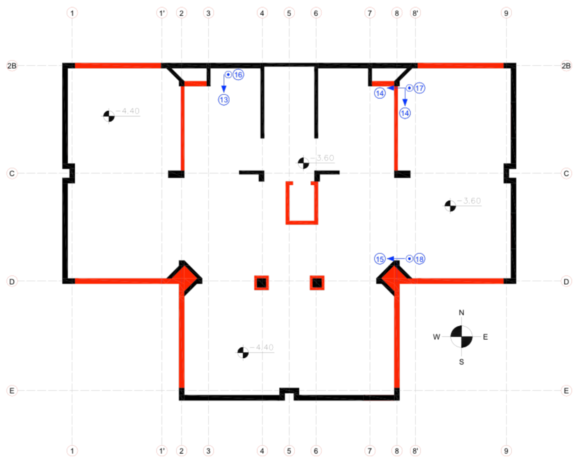
Figure 1 – View of the building from its southwest corner.

3. Instrumentation Scheme

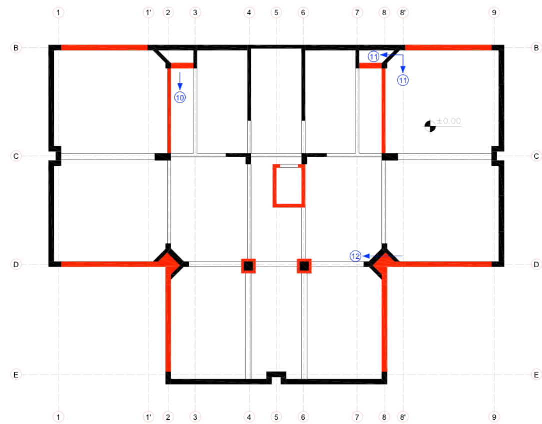
The building was excited along the E-W and N-S directions, respectively, by a vibration generator (Model VG-1; Kinemetrics, 1975; Fig. 3a) bolted to the fourth floor (one floor below the roof) slab between the elevator shaft and the stairs (Fig. 2f). The vibration generator applied a horizontal unidirectional sinusoidal force (in kN):

$$p(t) = 0.24f^2 \sin 2\pi f t \quad (1)$$

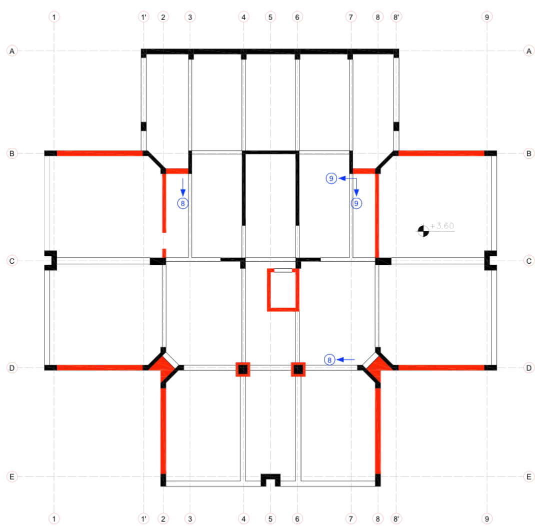
where f is the excitation frequency (in Hz) and t is the time (in s). Structural responses were monitored by a dense network of 18 uniaxial accelerometers (CMG-5U; Guralp Systems, 2013; see Fig. 2 for their locations; see Fig. 3b for accelerometer #3) deployed throughout the building. Three horizontal accelerometers were placed on the fourth and two basement floors, two parallel along the excitation direction and the third in the perpendicular direction, which made possible to record the translational and torsional responses of each of these floors. The first three floors were instrumented by two horizontal accelerometers, parallel along the excitation direction. The second basement floor was further instrumented by vertical accelerometers placed at three corners of the building to monitor the rocking responses of the building, if any. Accelerations were recorded at 100 samples per second, yielding a frequency range up to 50 Hz according to the Nyquist frequency criterion, by two six-channel digital recorders (CMG-DM24; Guralp Systems, 2009; Fig. 3c). Accelerometers placed along the excitation direction on the fourth and two basement floors were used as reference accelerometers and records from all 18 accelerometers were taken in two setups for each excitation direction. Table 1 shows the accelerometer locations and directions for all test setups.



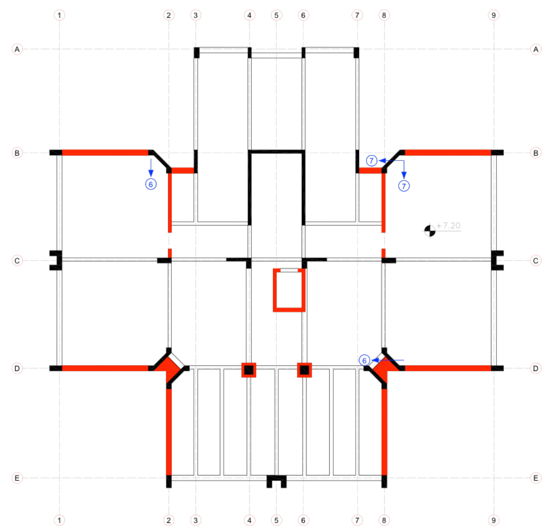
(a) Second basement



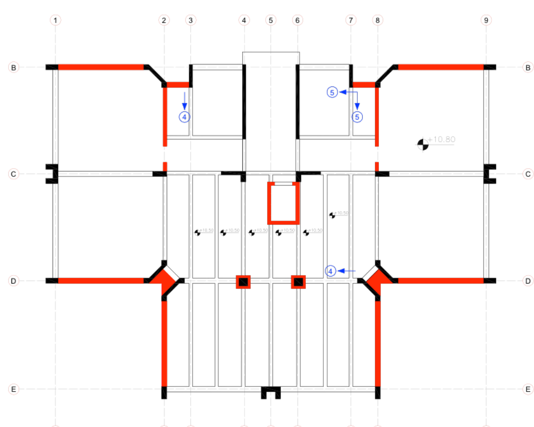
(b) First basement



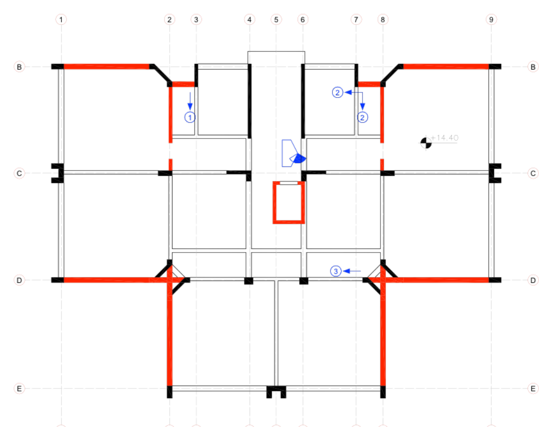
(c) First floor



(d) Second floor

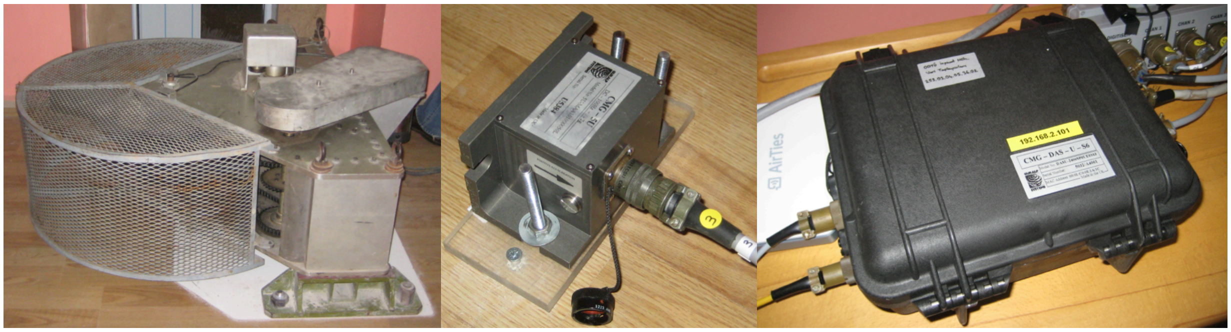


(e) Third floor



(f) Fourth floor

Figure 2 – Floor plans; instrumentation scheme.



(a) (b) (c)

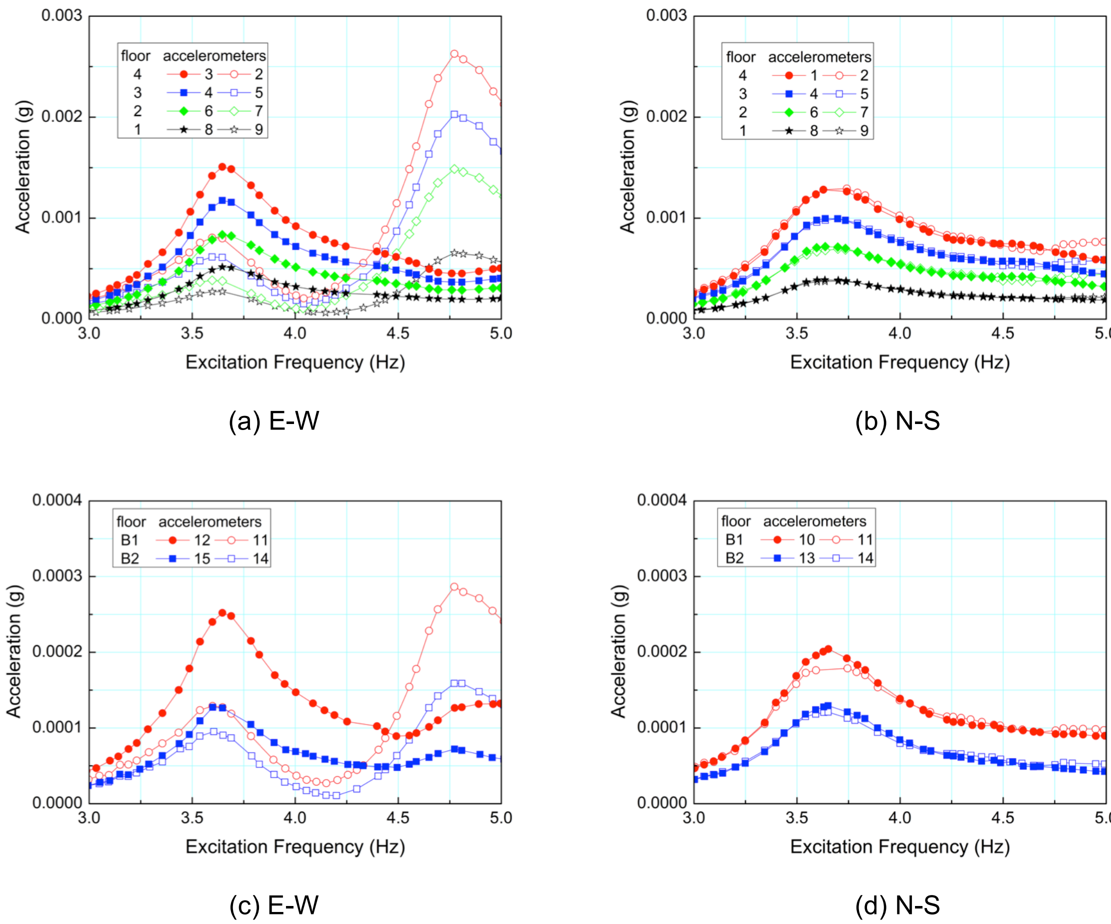
Figure 3 – (a) Vibration generator, (b) accelerometer #3, (c) data acquisition system.

Table 1 – Accelerometer locations and directions.

		E-W excitation				N-S excitation			
Acc. #	**Floor #**	**Loc.**	**Dir.**	**Setup 1**	**Setup 2**	**Loc.**	**Dir.**	**Setup 1**	**Setup 2**
1	4	B3	S		•	B3	S	•	•
2	4	B7	W	•	•	B7	S	•	•
3	4	D7	W	•	•	D7	W	•	
4	3	D7	W	•		B3	S		•
5	3	B7	W	•		B7	S		•
6	2	D8	W	•		B2	S		•
7	2	B8	W	•		B8	S		•
8	1	D7	W	•		B3	S		•
9	1	B7	W	•		B7	S		•
10	B1	B2	S		•	B2	S	•	
11	B1	B8	W	•	•	B8	S	•	•
12	B1	D8	W	•	•	D8	W	•	
13	B2	B3	S		•	B3	S	•	•
14	B2	B8	W	•	•	B8	S	•	•
15	B2	D8	W	•	•	D8	W	•	
16	B2	B3	+Z		•	B3	+Z	•	
17	B2	B8	+Z		•	B8	+Z	•	
18	B2	D8	+Z		•	D8	+Z	•	

4. Structural System Dynamic Properties

A frequency sweep up to 5.0 Hz with increments of typically 0.05 Hz was performed in the E-W and N-S directions, respectively, and the first translational modes in both directions and the first torsional mode were excited. Upon digital signal processing of the records, plotting the steady-state response amplitudes at each frequency, after the transient response damped out, resulted in frequency-response curves in the form of acceleration amplitude versus excitation frequency (Rea et al., 1968; Celik et al., 2015) as shown in Fig. 4 for the E-W and N-S excitations. Natural vibration frequencies, which are essentially equal to resonant frequencies (Rea et al., 1968; Chopra, 1995), were determined as 3.7 Hz for the first translational modes in both E-W and N-S directions, whereas the first torsional mode frequency was determined as 4.8 Hz. Associated damping capacities, ξ, as determined using the half-power bandwidth method (Rea et al., 1968; Chopra, 1995), were 6%, 9%, and 6%, respectively. Table 2 presents these structural system dynamic properties together with natural periods, T, as structural engineers usually prefer them to frequencies. Figure 5 shows the acceleration-frequency curves for the torsional responses



(a) E-W (b) N-S

(c) E-W (d) N-S

Figure 4 – Acceleration-frequency response curves for E-W and N-S excitations.

Table 2 – Structural system dynamic properties.

Mode	T (s)	f (Hz)	ξ (%)	Description
1	0.27	3.7	6	E-W translation
2	0.27	3.7	9	N-S translation
3	0.21	4.8	6	Torsion

of all floors, as determined from the E-W excitation, which confirm that the resonant frequency at 4.8 Hz is due to the torsional mode. Torsional responses were computed as the differences between the translational responses recorded by two parallel accelerometers divided by the distance between them. Acceleration-frequency curves for the rocking response of the building shown in Fig. 6 were determined similarly from the records of the vertical accelerometers in parallel at the second basement floor. Natural vibration mode shapes of the building can be deduced from the measured responses at resonant frequencies (cf. Figs. 4 and 5).

5. Conclusions

Structural system dynamic properties of a four-story reinforced concrete building with two basement floors, which is the first instrumented building in Turkey and nearby the North Anatolian Fault, were identified through its forced vibration test. First translational mode periods in both E-W and N-S directions, and first torsional mode period were determined together with associated damping capacities. These dynamic properties will later be used in validating and calibrating its state-of-the-art finite element model

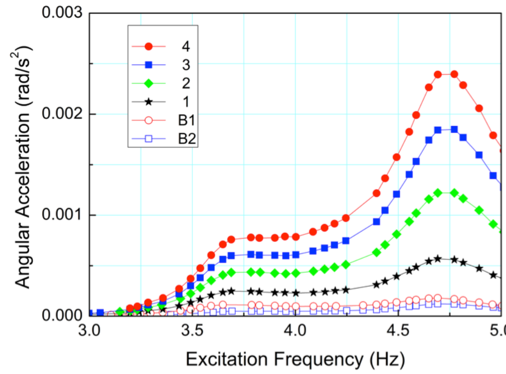


Figure 5 – Acceleration-frequency curves for torsional responses of all floors.

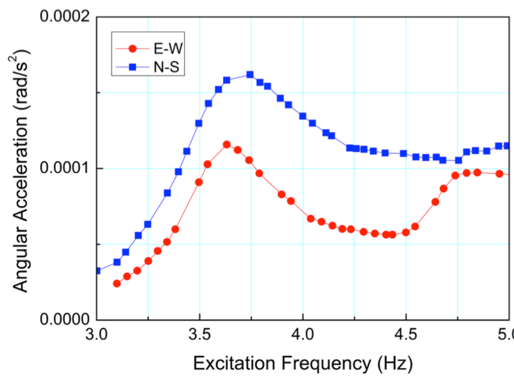


Figure 6 – Acceleration-frequency curves for rocking response of the building.

for small-amplitude motions. To start off with a reliable structural model that will form the basis for subsequent nonlinear time history analyses typically required in deriving seismic fragility curves (Celik and Ellingwood, 2009; 2010) is expected to also lead to reliable seismic risk assessment of this instrumented building. The objective in testing instrumented buildings in earthquake prone areas of Europe as part of a European Union project is to validate the derived fragility curves in the long run when structural responses of these buildings to future earthquakes are recorded.

6. Acknowledgements

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