EXERCISE-INDUCED BUILDING VIBRATIONS: A MODERN-DAY HAPPENING

Gerry Pernica, Institute for Research in Construction, National Research Council of Canada, Ottawa, Ontario, K1A 0R6

INTRODUCTION

Rhythmic exercises in a small gymnasium on the top storey of a recently constructed office tower in downtown Ottawa were considered responsible for producing annoying vibrations in the upper floors of the 26-storey concrete building. The gymnasium was built and operated by a tenant which leased the top half of the office tower. The exercises, jumping, jumping jacks, side-to-side stepping, etc., were part of a corporate aerobics class which began each day at noon. The 1-hour class was generally well attended containing upwards of 50 participants. However, as in most office buildings, not all employees broke for lunch at the same time. Those who worked while the aerobics class was in progress found the induced floor vibrations in the upper storeys of the building highly annoying.

For operational reasons, management wanted the aerobics classes to continue but not at the expense of staff productivity. They, therefore, sought schemes to reduce the dynamic response of the floors to the rhythmic activities taking place in the gymnasium. This paper briefly describes the investigation that was undertaken i) to identify the structural elements within the building undergoing resonant or near-resonant behaviour during the classes and ii) to recommend appropriate remedial measures (tuned mass dampers, stiffening of floor elements) to rectify the situation.

BUILDING DESCRIPTION

The reinforced concrete building consisted of a central core of bidirectional shear walls which enclosed elevator shafts, strairwells and restrooms, and two rows of columns around the perimeter of the building (Fig. 1). Column spacings within the 40.8 m square, nearly symmetrical building ranged from 6.7 m to 9.1 m and column heights from 3.6 m (above 3rd storey) to 4.0 m. Column cross-sectional areas decreased with building height from 0.91 m^2 to 0.31 m^2 for the inner row of columns and from 0.68 m^2 to 0.22 m^2 for the outer row of columns. At each floor level, the columns supported 230 mm thick flat slabs which deepened to 340 mm over a 1.2 m wide strip along the perimeter of the building.

The gymnasium was situated at the south-west corner of the building between the two rows of columns (Fig. 1). Its floor was covered by a 6 mm thick rubber pad which was glued to the concrete slab. Aerobics classes were conducted in the western half of the gym which was separated from the neighbouring mechanical room by a full-storey blockwall partition. Other partitions in the upper storeys of the building were primarily of steel stud-drywall construction. However, most of these lightweight walls did not extend to the underside of the next floor slab but stopped just above the height of the suspended ceilings.

MEASUREMENT PROCEDURE

Vibration measurements were made to determine i) the natural frequencies of several of the concrete floor slabs in the upper storeys of the building and ii) the frequencies of the annoying vibrations induced in the floor slabs by rhythmic exercises during the aerobics classes.

Floor vibrations produced by instrumented hammer impacts, electrodynamic shaker inputs and ambient sources of excitations, were used to identify the natural frequencies of the concrete slabs. Hammer impacts were performed at several floor locations on the 25th storey directly below the gymnasium and harmonic shaker excitations (3 Hz to 13 Hz) at one location in the gymnasium.

Floor vibrations induced by staged rhythmic jumping at discrete frequencies from 2.0 Hz to 2.6 Hz were also measured to observe the sensitivity of the floors to exercise frequency. The exercises were performed in the gymnasium by two groups of people (two and eight participants) jumping in unison for at least 30 seconds at each frequency.

Vertical vibrations at the centre of several perimeter bays in the south-west corner of the building were measured on storeys 19, 22, 25 and 26. Measurements were made using servo-accelerometers having a sensitivity of 5 volts/gravity from 0-300 Hz. The accelerometers were taped either to aluminum plates which were epoxied to the underside of the floor slabs or to steel plates which were fitted with adjustable spike legs to penetrate the carpeting covering the floors in most office areas. Signals were amplified, low-passed filtered at 25 Hz and recorded on a multi-channel fm tape recorder for later analysis.

ANALYSIS PROCEDURE

Recorded signals were analysed on a 2-channel, narrowband frequency analyser. Natural frequencies of floor slabs on the four storeys were determined from Fourier spectra of hammer impacts and ambient excitations. Shaker excitations were ignored because the shaker (maximum force of 134 N) was unable to induce floor responses with good signal to noise ratios at most accelerometer locations. Dominant frequencies induced in the floor slabs during aerobics classes and staged rhythmic jumping were identified from Fourier and coherence functions.

RESULTS

Analyses indicated that i) the fundamental bending frequencies of the concrete slabs, about 10 Hz for each floor area, were substantially above the beat frequencies of the rhythmic aerobic exercises (1.8 Hz to 2.4 Hz) and the staged jumping exercises (2.0 Hz to 2.6 Hz); ii) the dominant frequency component of floor response during rhythmic activities occurred at twice the beat frequency of the activity and not at a higher harmonic in the vicinity of the fundamental bending frequencies; iii) the floors exhibited additional modes below 10 Hz with natural frequencies in the vicinity of the second harmonic of the rhythmic activities; iv) these modes were not simply other types of individual floor modes but vertical modes of vibration of the entire 26-storey building; and v) the lowest building modes (namely, 4.2 Hz, 4.4 Hz, 5.1 Hz and 5.5 Hz) were being strongly excited by the second harmonic of rhythmic activities during aerobics classes.

Calculations, assuming a vertical stress of 6.5 MPa in the two rows of columns throughout the height of the building, yielded a vertical building frequency of about 4 Hz. The floor vibration problem was, therefore, a resonant phenomenon associated with the dynamic properties of the entire 26-storey building and not simply those of floor slabs in the upper storeys of the building.

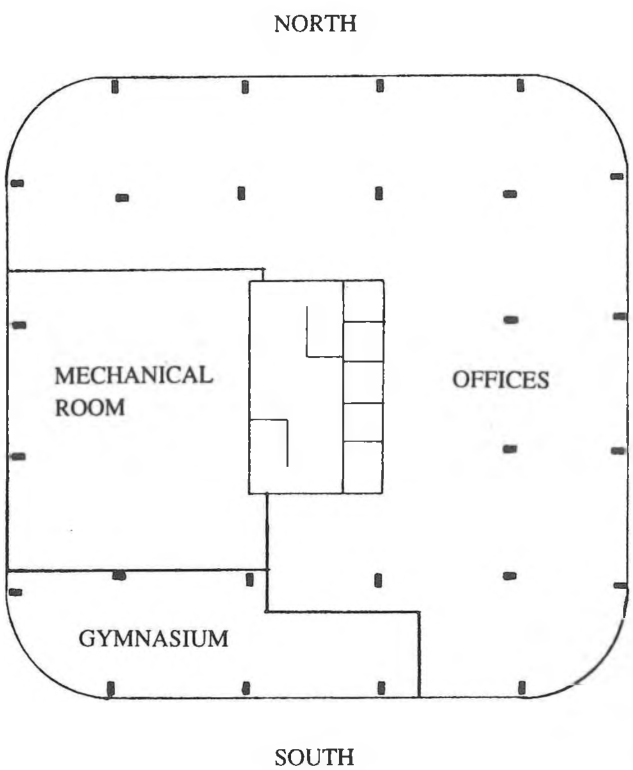

Figure 1 Layout of Structural Elements and Rooms on 26th Storey of Concrete Office Building

REMEDIAL MEASURES

The installation of tuned mass dampers to decrease the resonant floor responses of the building was not a practical solution because of the number of building modes that would need dampers and the large mass required for each of these dampers to be effective [1, 2]. Stiffening the building to raise its vertical natural frequencies was also impractical since significant changes to the building's vertical support system would be required.

Remedial measures included i) relocating the gymnasium to a much lower location within the building or nearer its central core to reduce the effects of the rhythmic forces in exciting the vertical modes of the building; ii) restricting the step frequency or beat of the rhythmic exercises to 1.5 Hz or less so that near-resonant/resonant effects are significantly reduced; and iii) changing the format of the aerobics class from a high to a low impact exercise program.

REFERENCES

1. Allen, D.E. and Pernica, G. 1984. A Simple Absorber for Walking Vibrations, Canadian Journal of Civil Engineering, Vol. 11, 1984, p. 112-117

2. Smith, J.W. 1988. Vibrations of Structures, Applications in Civil Engineering Design, Chapman and Hall, 29 West 35th Street, New York, NY, 10001, 1984, 338 p.