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DYNAMIC BEHAVIOUR OF FLAT POST-TENSIONED FLOOR PLATES

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Abstract

Vibration is a serviceability limit state for the design of suspended floor systems in buildings that is not well understood by many structural engineers. Dynamic behaviour is an important design consideration for slender, two-way floors, particularly for those of post-tensioned concrete construction. At present, there are no reliable design guidelines that deal with this problem. This paper describes a research program on the dynamic behaviour of post-tensioned concrete floors that is presently underway at Queensland University of Technology in Brisbane, Australia. Results from this research will enable the development of much needed design guidance on the dynamic behaviour post-tensioned concrete floors in buildings.

A full-scale, post-tensioned slab specimen has been constructed in the university's structural laboratory. Purpose-designed support brackets have been fabricated which have enabled an investigation on the effects of various support conditions at the corners of the specimen. A series of static and dynamic tests are being performed in the laboratory to obtain basic material properties and behavior of the specimen. Data collected from these experiments will be used to tune finite element models for computational, parametric studies. Preliminary finite element analyses of both composite and homogeneous material cross-sections have been calibrated against results from initial laboratory experiments. Further field instrumentation and testing of floors in existing buildings will be conducted to validate computational studies. These computational studies will be expanded to generate predictive guidelines for the free vibration and response of two-way, post-tensioned concrete floors.

Eds.: J. Eberhardsteiner, H.A. Mang, H. Waubke

INTRODUCTION

The response of a floor to dynamic loading is directly related to and heavily dependent on the natural frequency of the floor itself. Predictive determination of the natural frequency of a floor structure is crucial for assessing its dynamic serviceability during the design phase of a project. Without the ability to predict the dynamic performance of floors, vibration assessment becomes retrospective. If vibration is determined to be a serviceability problem after the floor has been constructed, then costly structural retrofit could be required that may disrupt or alter the originally intended function of the tenancy.

Among a number of studies that address this issue for composite, steel-framed floors, two very successful design guides have been published in the United Kingdom and North America that are commonly referred to and used in practice [1,2]. The reason these guides are successful in accessing the dynamic serviceability for this type of floor construction is that they provide reasonably accurate methods for calculating the natural frequency of a floor panel. Research focused on the dynamic behavior of cast-in-situ concrete floors is limited, particularly for post-tensioned systems. The only available formal guideline for the dynamic analysis and design of post-tensioned system is the Concrete Society Technical Report 43 (CSTR43) of 1994 [3]. Since it's publication, there have been reports that it produces over conservative designs when used for assessing vibration serviceability, primarily a result of the CSTR43 method having the tendency to underestimate the natural frequency [4-6].

This paper will describe the promising, preliminary outcomes of a frequency factor approach to predicting the natural frequency of post-tensioned floors.

OVERVIEW OF LABORATORY TEST SET-UP

In order to ensure adequate development of anchorages and minimize stress losses in the steel strands the minimum length for a tendon in a post-tensioned floor structure is approximately 5.5m as a rule-of-thumb. . To simulate a typical slab geometry encountered in actual structures and to work within the confines of the reaction floor, a 170mm thick, square specimen with 5.7m spans was constructed in the university's structures laboratory. The specimen was designed for factored, super imposed dead and live loads of 1kPa and 2kPa respectively. The overall geometry and post-tensioning plans are shown in Figure 1.

One of the unique features of this test specimen is the support system, which is designed to provide pinned and fixed support conditions. The specimen is supported on its corners by four steel support brackets. The specimen was cast directly onto 20mm sandwich plates that were placed freely on the top of each support bracket. To achieve a pinned connection, a hardened, high-strength steel nut was welded to the underside of the 20mm top plate of each support bracket. A round-tipped, high strength bolt is then turned through the nut until the sandwich plate is raised above the top plate. In this position, the specimen is supported entirely by the virtually frictionless point contact between the tip of the bolt and the sandwich plate. Figure 2 shows the support brackets in the pinned position. For a fixed connection, four 25mm PVC sleeves were cast into each corner of the specimen. Then 20mm threaded structural steel rods are placed through the sleeves and holes in the sandwich plate and support bracket. The rods are then stressed from each end with structural grade nuts. Fixed support tests will not be discussed in this paper.

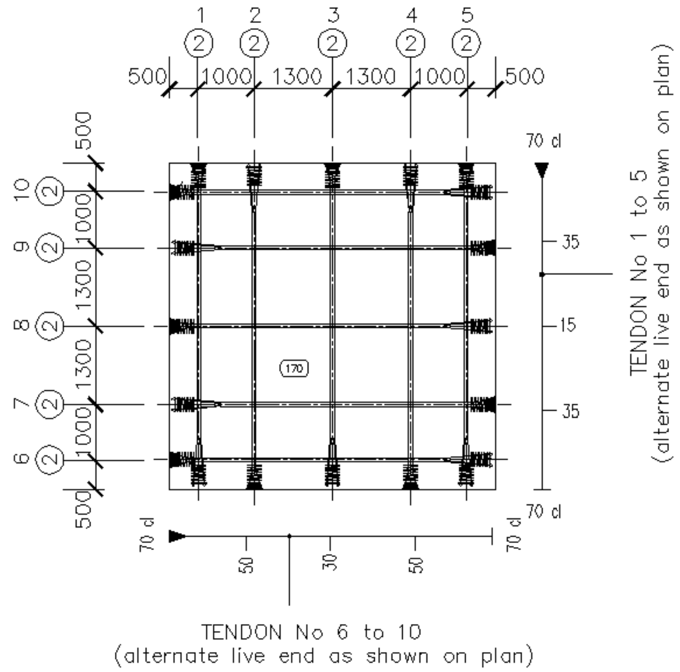

Figure 1 – Post-tensioned Laboratory Floor Specimen

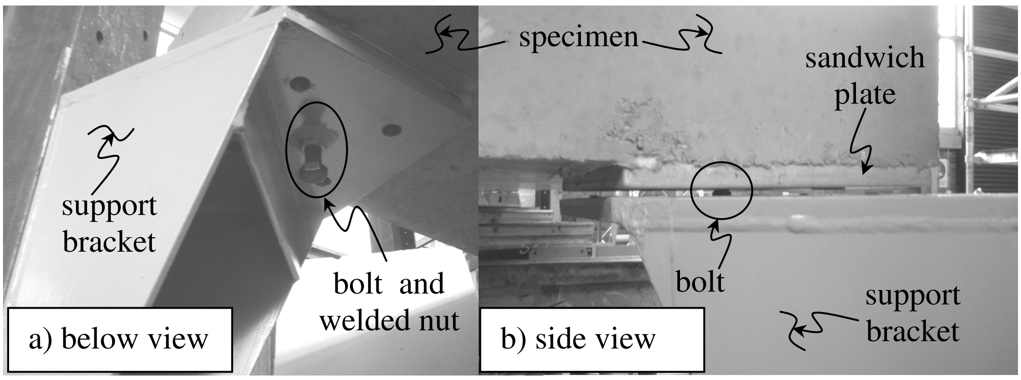

Figure 2 – Support Bracket in Pinned Position

Preliminary laboratory tests on the free vibration of the specimen with pinned supports have been completed. These tests were performed by employing the simple heel-drop. Time-history acceleration records from preliminary laboratory tests in conjunction with preliminary finite element analyses have been useful in estimating the damping ratio, ζ, and the dynamic modulus of elasticity, E_{dyn}, for the pin-supported specimen.

PRELIMINARY FINITE ELEMENT ANALYSIS

Composite and Homogeneous Modeling

Because real post-tensioned floors are comprised of concrete and stressed steel tendons, it is necessary to model composite elastic behavior with a homogeneous material cross-section for efficient finite element analysis (FEA).

First, the elastic stiffness, of simply supported one-way and two-way floor systems having the same span-to-depth ratios, was studied using a composite material finite element model (FEM). Four-node, shell elements were used to model the concrete and two-node, cable elements were used to model the steel post-tensioning strands. Composite behavior was simulated by using link elements between the cable and shell element nodes for lateral and transverse degrees of freedom. Three independent load cases were considered: self-weight, post-tensioning and concentrated mid-span load, say 'P '. The performance of the one-way, system FEM was gauged to have extremely high accuracy by comparing hand calculated top and bottom fiber stresses to those calculated from FEA for each load case. The same degree of accuracy was assumed for the two-way, system FEM. Then the elastic stiffness was taken as the load-deflection ratio, P/Δ, where 'Δ' is the deflection caused by the load 'P ' subsequent to the initial deflection from the combination of self-weight and post-tensioning.

The next step was to study the elastic behavior using homogeneous FEMs. In this case, only four-node, shell elements were used to model the concrete. The same geometry and values for the concrete density and modulus of elasticity assumed for the composite FEM were used. Only two independent load cases were considered: self-weight and a concentrated mid-span load, 'P '. Then the elastic stiffness was taken as the load-deflection ratio, P/Δ, where 'Δ' in this case is the deflection caused by the load 'P ' subsequent to the initial deflection from self-weight.

Although the total deflections from homogeneous modeling were slightly higher, a comparison of the composite and homogeneous finite element models showed that the difference in elastic stiffness was less than 0.5% for one-way systems and less than 0.05% for two-way systems. Considering that AS3600, Clause 6.1.2, recognizes that the values for the modulus of elasticity for concrete may vary between (+/-)20.0%, it was determined reasonable for this study to proceed with dynamic FEA using homogeneous finite element modeling [7].

Dynamic Finite Element Analysis

A finite element model of the laboratory specimen was calibrated against results from the preliminary laboratory testing, allowing the dynamic modulus of elasticity, E_{dyn}, and the damping ratio, ζ, of the specimen to be estimated.

The dynamic modulus elasticity was determined to be E_{dyn} = 33.3 GPa. There are two interesting points to note:

1) E_{dyn} = 33.3 GPa is only 0.4% greater than code calculated elastic modulus, E = 32.0 GPa. This is interesting because the recommended dynamic modulus is 35.0% greater than the code calculated elastic modulus [2].
2) The actual average values for compressive strength, f'_c = 44.6 Mpa, and density, γ=2367 kg/m^3, were measured from 28 day cylinder tests. If these measured values for strength and density had been used in estimating the dynamic modulus of elasticity, the result would have been, E_{dyn} = (1.35) x 33.1 GPa = 44.6 GPa. This difference corresponds to a 34.0% overestimate of the dynamic modulus (*much greater that the 20.0% code provision*).

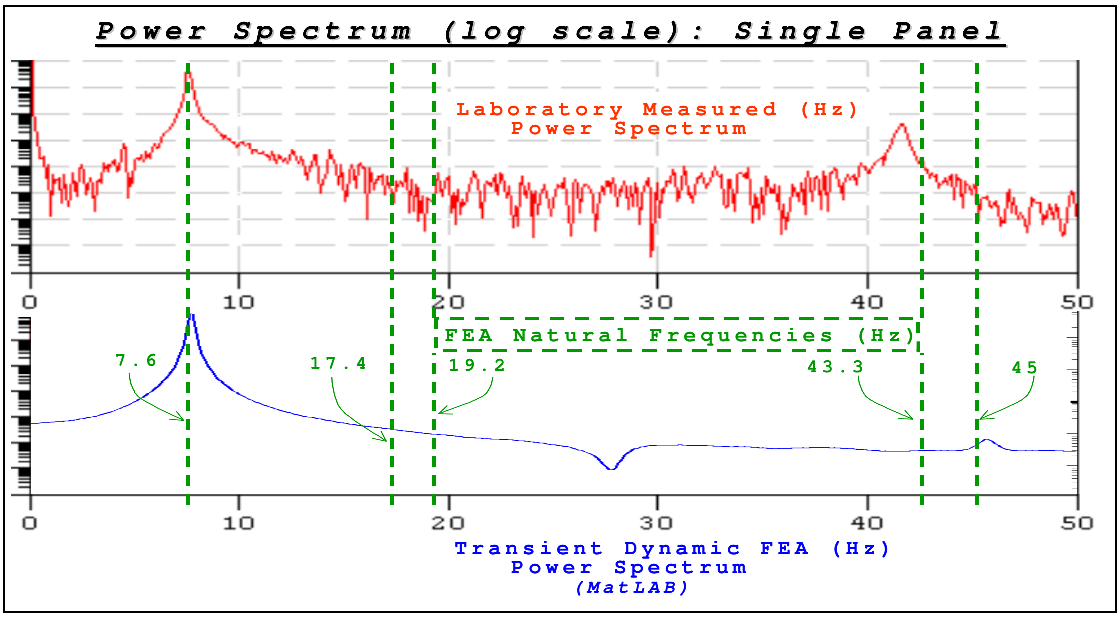

Figure 3 –Measured and Calculated Power Spectra with Eigenvalue Natural Frequencies

Determination of the dynamic modulus was accomplished by adjusting the FEM modulus until the eigenvalue first-mode natural frequency matched the Fourier spectral density function obtained from laboratory tests. Figure 3 shows the comparison of measured and calculated power spectra against the first five eigenvalue natural frequencies after the damping ratio had been determined. This figure illustrates that the calibrated finite element model shows excellent agreement with the laboratory tests, particularly with regard to the primary response of 7.6Hz. It can also be observed that the measured power spectrum exhibits a peak at ~41Hz. This 8.5% reduction in the 5th mode eigenvalue of 45Hz was predicted from FEA in which the laboratory columns were included in the FEM.

Because displacements were not measured during these preliminary laboratory tests, direct application of the logarithmic decrement method was applied to the acceleration time-history record for evaluating the damping ratio. In addition, the damping parameter in the FEA was adjusted until the computed decay of acceleration from a transient dynamic analysis showed good agreement with the time-history acceleration record. This approach resulted in a damping ratio of ζ =1.2%, which is typical for an unfinished floor structure.

RESEARCH OBJECTIVE

Developing predictive, analytical guidelines for post-tensioned floors is the essence of this research. One of the aims of this research is to develop a frequency factor method for predicting the fundamental frequencies of post- tensioned floors. Observations have been made from preliminary FEA on multiple panel floors during this research may provide insight on the dynamic analysis of post-tensioned floor structures. Ones intuition may lead to an expectation that the free vibration response of a floor to transient excitation, like a heel-drop, should correspond to the first-mode natural frequency calculated from an eigenvalue analysis. This is not always true. Three finite element models of a nine-panel floor with a square support grid were analyzed for transient dynamic response and eigenvalue natural frequency. The panel span-to-depth ratio was held constant at, *S/d* = 33.5, which is the same as for the single panel specimen. The individual panel dimensions were 5.7m, 9.0m and 12.0m with corresponding stiffness-to-mass ratios of '$\lambda = (EI)/(L^4m)\ rad/s^2$' = 33.7, 12.7 and 7.1 respectively. Three separate transient dynamic analyses were conducted on each of the three models by applying a heel-drop excitation to the side, center and corner floor panels. Eigenvalue natural frequency analysis was also conducted for each model. The power spectra resulting from transient analyses corresponding to a center panel heel-drop excitation and eigenvalue frequencies for each of the three finite element models for this case are presented in Figure 4.

It turns out that the primary free vibration response of the center panel, for this special case, dominantly corresponds to the 9th (ninth) eigenvalue natural frequencies. Similar trends were also apparent from the analyses conducted on the side and corner panels. By plotting the primary frequency response for each case against the stiffness-to–mass ratio, λ, the resulting frequency factors are easily derived as C_{centre}= 6.82, C_{side}= 5.56 *and* C_{corner}= 4.87. The accuracy of these factors is graphically illustrated in Figure 5.

CONCLUSION

The preliminary, computational experiments described above clearly illustrate that primary free vibration response from a transient dynamic excitation does not necessarily correspond to the first-mode eigenvalue natural frequency. In conclusion, this research will exploit an opportunity to develop empirical guidelines for the dynamic behavior of post-tensioned floors, partially through the use transient dynamic analysis. Future studies will consider the contribution of column and wall supports to the overall system dynamic behavior for various floor panel aspect ratios.

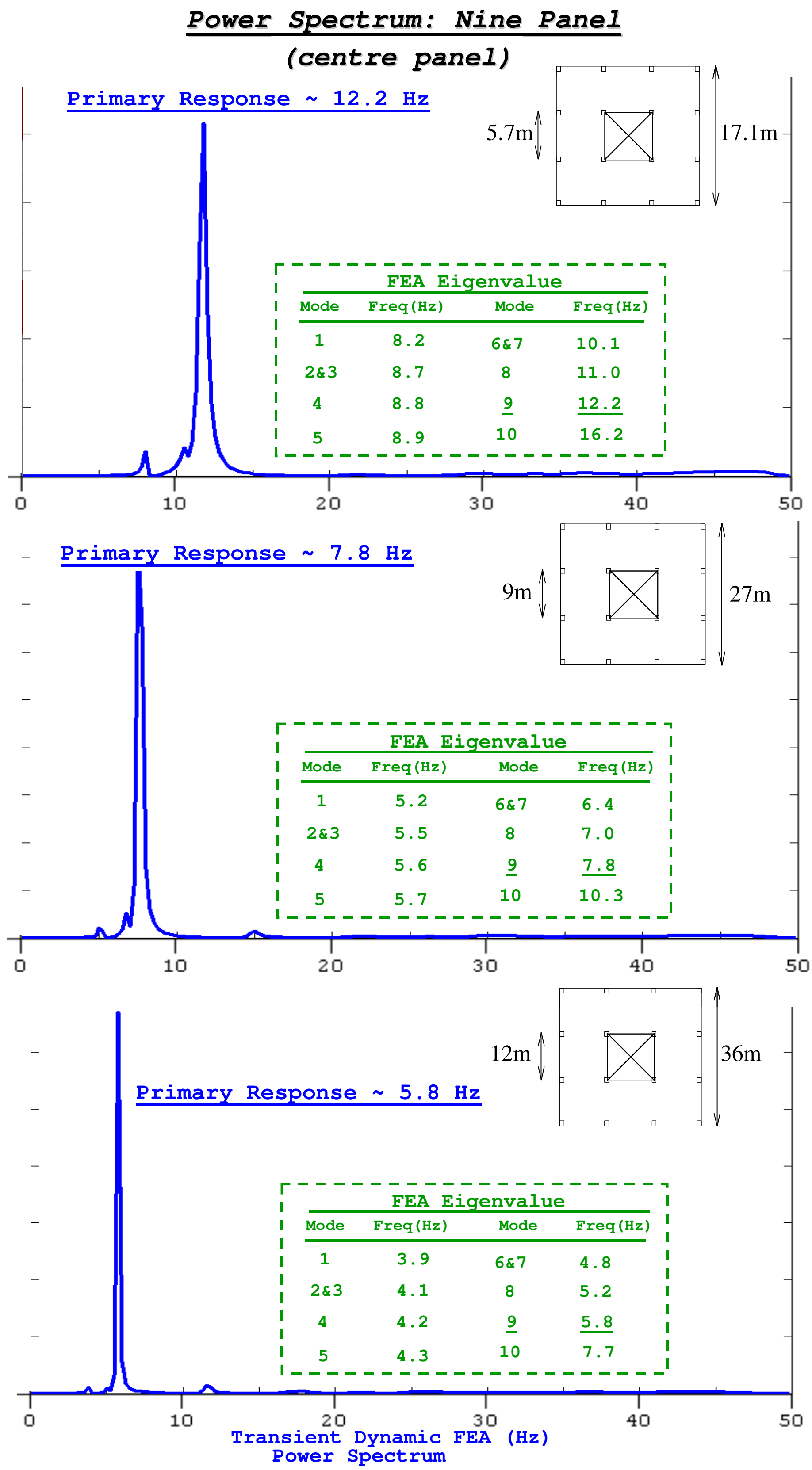

Figure 4: Transient and Eigenvalue FEA for a 9-panel Floor

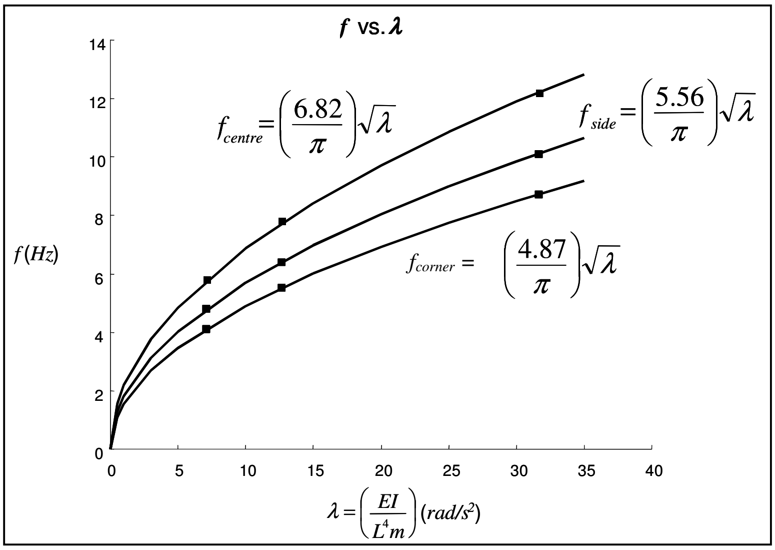

Figure 5: Transient and Eigenvalue FEA for a 9-panel Floor

ACKNOWLEDGEMENTS

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REFERENCES

1. Wyatt, T.A., Design Guide on the Vibration of Floors. Construction Industry Research and Information Association, ed. S.C. Institute. 1989, London, UK: Berkshire. UK.
2. Murray T. M., A.D.E., Ungar E.E., "Floor Vibrations Due to Human Activity." American Institute of Steel Construction, Steel Design Guide Series. Vol. 11. 1997, Chicago, Ill.
3. CSTR 43. Post-Tensioned Concrete Floors - Design Handbook: Technical Report 43. 1994, Slough, UK: Concrete Society.
4. Caverson R.G., W.P., Williams M.S., Review of vibration guidelines for suspended Concrete Slabs. Canadian Journal of Engineering, 1994.
5. Pavic, A., Reynolds, P., Waldron, P. and Bennett, K. J., Critical Review of Guidelines for Checking Vibration Serviceability of Post-tensioned Concrete Floors. Cement and Concrete Composites., (2001). Vol. 23(No. 1): p. pp. 21-31.
6. Williams, M.S., and WaldronP., Evaluation of Methods for Predicting Occupant-induced Vibrations in Concrete Floors. The Structural Engineer, 1994. 72(20): p. 334-340.
7. AS (2001). AS 3600-2001, Standards Australia.