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Influence of Concrete Cracks on Floor Vibration

Influence de la fissuration sur la vibration des planchers en béton

Einfluss der Rissbildung auf die Schwingung von Betondecken

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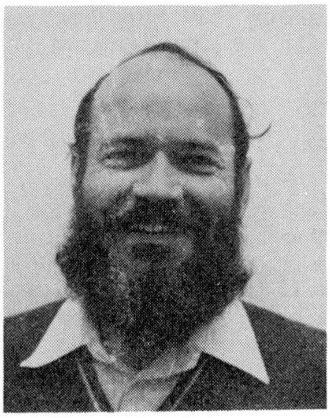

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SUMMARY

The vibration of suspended floors, generated by various human activities, is widely recognised as an important serviceability criterion. Cracked slabs have a reduced stiffness, leading to greater static deflection and lower natural frequencies, both of which detrimentally influence vibration. Measurements of isolated slabs and complete floors, together with a theoretical analysis, are used to quantify the effect of cracking.

RESUME

Les vibrations résultant d'activités humaines sur les planchers suspendus représentent un critère d'aptitude au service largement admis. La fissuration de dalles en béton entraîne une réduction de la rigidité et, de ce fait, une augmentation des flèches sous charge statique et une diminution de la fréquence propre; ces deux derniers facteurs influencent négativement le comportement aux vibrations d'un élément porteur. Les mesures effectuées sur des dalles isostatiques et des systèmes hyperstatiques de planchers, combinées à l'analyse théorique, servent à quantifier les effets de la fissuration.

ZUSAMMENFASSUNG

Durch menschliche Tätigkeiten hervorgerufene Schwingungen sind ein anerkannt wichtiges Gebrauchstauglichkeitskriterium für abgehängte Geschossdecken. Der Steifigkeitsabfall in Betonplatten infolge Rissbildung führt zu grösserer statischer Durchbiegung und tieferen Eigenfrequenzen, was beides das Schwingungsverhalten nachteilig beeinflusst. Messungen an Einzelplatten und Deckensystemen werden zusammen mit theoretischer Analyse dazu verwendet, den Einfluss der Rissbildung zu quantifizieren.

1. INTRODUCTION

It is increasingly evident that floor vibration in office and residential buildings is an important serviceability consideration, particularly when dealing with light long span floors. Several recent studies have been reported on this topic [1,2,3,4].

Many different factors influence the vibration amplitudes which may be experienced, one of which is the stiffness of the floor structure. Typically floors are constructed in concrete or compositely. The concrete may be either conventionally reinforced or pre-tensioned. The stiffness of concrete is significantly influenced by any cracking of the concrete, whether this is due to shrinkage or stresses exceeding the tensile strength of the concrete. It is thus of interest to investigate the influence of this cracking on the vibration characteristics of the concrete portion of floors.

2. MEASUREMENTS OF BEHAVIOUR

Physical measurements of isolated concrete slabs and of completed floors in two buildings are reported. The measurements on the isolated slabs facilitate an understanding of the direct influence of cracking of concrete slabs, whilst the measurements on complete building floors give allow an overview of the broader implications of cracking of concrete.

2.1 Isolated precast slabs

Two different types of hollow precast concrete slabs have been tested in a simply supported condition using a span of 2,38 m and a central line load across the full width of the slab. This testing layout is shown in the photograph in figure 1.

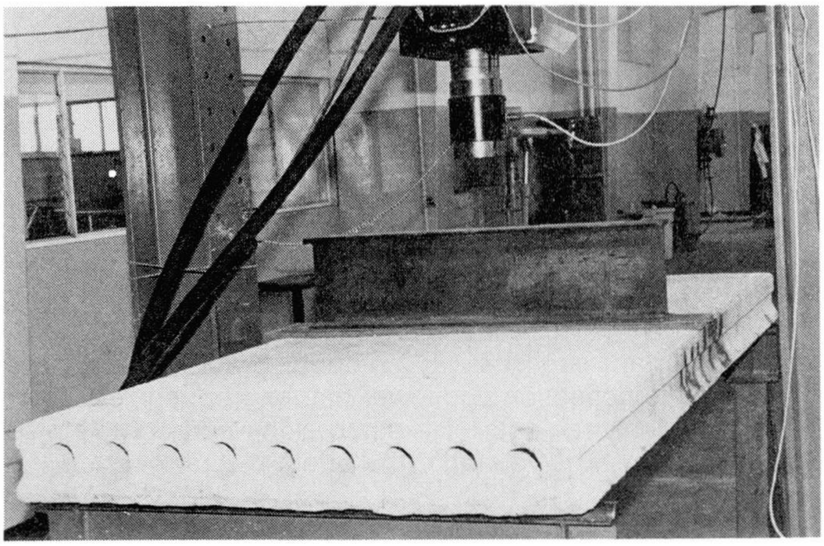

Figure 1: Photograph of Slab Testing Layout

2.1.1 Tests Conducted

In both cases, a total of three different tests was conducted. These were as follows:

(a) Dynamic test on the uncracked slab, to establish dynamic stiffness and the fundamental natural frequency.
(b) Static test to the ultimate load of the slab.
(c) Dynamic test on the cracked slab, to establish the new dynamic stiffness and fundamental natural frequency.

In the measurement work on some of the slabs, tests (a) and (c) were done at both a low level of static load, giving a stress which remained below the prestress, and at a high level of static load, giving a stress exceeding the prestress. Typical dynamic stiffness results are shown in figure 2. These dynamic stiffness values are calculated by plotting load vs deflection and calculating the slope of the resulting graph. The natural frequency is taken as that frequency at which the dynamic stiffness curve passes through 0, ie where the phase angle between load and deflection changes sign.

2.1.2 Slabs Tested

Tests on a total of three nominally identical prestressed slabs are reported. These slabs are 1170 mm wide and 155 mm deep with 10 steel tendons of 5 mm diameter

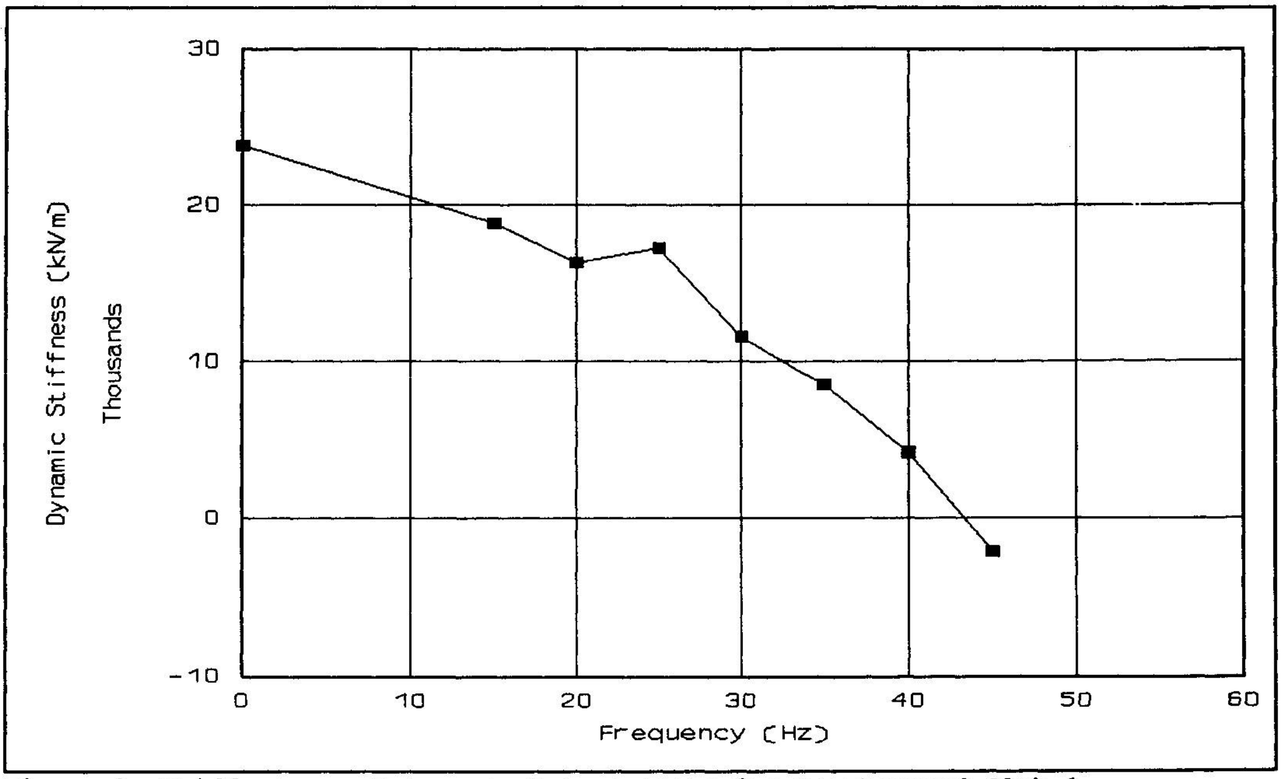

Figure 2: Stiffness vs Frequency Measurements for Prestressed Slab 1

at e depth of 130 mm. The measured mass, static stiffness, and fundamental natural frequency for each of the prestressed slabs are listed in table 1.

Tests on a total of two nominally identical plain reinforced slabs are also reported, and the results are listed in table 1. These slabs are 890 mm wide and 150 mm deep having 7 reinforcing bars of 6 mm diameter at a depth of 140 mm.

2.1.3 Influence of Vibration on Cracks

In no case is there any evidence of an influence on the crack size due to the applied vibration stresses. The vibration loads in the tests quoted have a magnitude of between 10% and 35% of the load required initially to crack the concrete. The test procedure prior to cracking of the beam requires that the beam be subjected to approximately 20000 cycles of this load, which has not shown any initiation of cracking. Subsequent to cracking the beam is subjected to approximately a further 30000 cycles, again showing no obvious extension of the crack size.

2.2 Floors in completed buildings

Vibration test on floors in two different buildings are reported here. The tests in each building are on floors of nominally identical construction, but differing in load history, and having different levels of static load. The construction of both buildings is complete. In both cases tests are reported for an unoccupied area with thin carpet finishes only, and for a fully furnished and occupied office area. There are thus differing levels of cracking. In both cases the load applied is an impulse load obtained by dropping a specified mass 200 mm onto a rubber pad. This load is designed to approximate a heel drop load, but is applied over a shorter time period of 0,02 s. The applied load and the floor acceleration at mid-span of the slab and at quarter span in both directions are recorded.

Tests on two buildings are reported. Building 1 has a continuous cast-in-situ flat floor slab which is 150 mm thick, and which has one way post-tensioning. The span between columns is 5 m in both directions. The mass dropped in these tests is 4 kg. The fully occupied area in this building is a library area with full height partitions along the column lines and heavy shelving containing books along two sides. The measured loads and peak acceleration responses are listed in table 2.

Slab Test	Condition	Mass kg/m	Stiffness kN/m		Fundamental Freq. Hz	
			Low load	High load	Low load	High load
Prestressed 1	Uncracked	338	22727	22727	40	-
	Cracked	338	-	2725	42	-
Prestressed 2	Uncracked	334	23810	-	43	-
	Cracked	334	-	4200	-	25
Prestressed 3	Uncracked	331	22571	25240	48	52
	Shallow crack	331	22105	10015	-	-
	Deep crack	331	22105	3162	46	24
Reinforced 1	Uncracked	224	8924	8924	33	-
	Cracked	224	3175	3175	22	-
Reinforced 2	Uncracked	229	11911	11911	40	-
	Cracked	229	6804	5972	28	29

Table 1: Results of Isolated Slab Tests

It is found that the 4 kg mass does not impart sufficient energy to this floor to enable any assessment of natural frequency to be made.

Building 2 has a floor which consists of 150 mm thick plain reinforced precast slabs, simply supported and spanning 5.7 m between steel beams. The steel beams are 457x152x60 kg/m I sections, which span 6.34 m. The mass dropped in these tests is 10 kg. The fully occupied area in this building is a high density general office area, with 1,2 m high partitions at approximately 3 m centres defining work areas for four people. The measured loads, natural frequencies, and peak acceleration responses are listed in table 2.

Building	Floor Occupancy	Peak Load kN	Natural Freq. Hz	Peak Accel. m/s^2
Cast-in-situ post-tensioned slab	Unoccupied	2,7	-	0,5
	Library	2,7	-	4,0
Plain reinforced precast slabs	Unoccupied	5,4	8,5	2,3
	Dense office	4,9	7,8	3,1

Table 2: Measured Full Floor Responses

Of particular interest with the measurements recorded in table 2, is to assess them against some acceptability criteria. A convenient criterion is that defined by SABS0162 [5], which permits a peak acceleration of, say 1,2 m/s^2 if a fairly high level of damping exists. It can be seen in table 2 that in both cases the acceleration amplitude is higher on the occupied floor, and in the case of the post-tensioned floor the acceleration on the unoccupied floor is acceptable, whereas that on the occupied floor is no acceptable.

3. THEORETICAL ANALYSIS

The theoretical study concentrates on a simple computer based analysis of the response of floor slabs equivalent to the prestressed slabs tested. This theoretical analysis is done using three different crack conditions and two different dynamic loads. The different crack conditions considered are:

- uncracked.
- a crack extending 55 mm above the beam soffit.
- a crack extending 105 mm above the beam soffit.

The beams are modelled as five separate elements, making up a simply supported beam as shown in figure 3, with a span of 2,38 m. All the elements are modelled with the measured mass per metre and an elastic modulus of 27 GPa. In order to introduce a more realistic span length, the analysis is repeated for an assumed span of 5,0 m. The outer two elements at each end of the beam are modelled with the full second moment of area, which is $0{,}335\times10^{-3}$ m^4. The cracking of the concrete will lead to localised variations in the stiffness, which is modelled in the central element, which has a second moment of area which is reduced to $0{,}090\times10^{-3}$ m^4 and $0{,}0278\times10^{-3}$ m^4 for the two different crack depths used. The length of the central element is assumed to be equal to the depth of the beam on each side of the crack, to allow for the full development of strains in the remaining uncracked concrete.

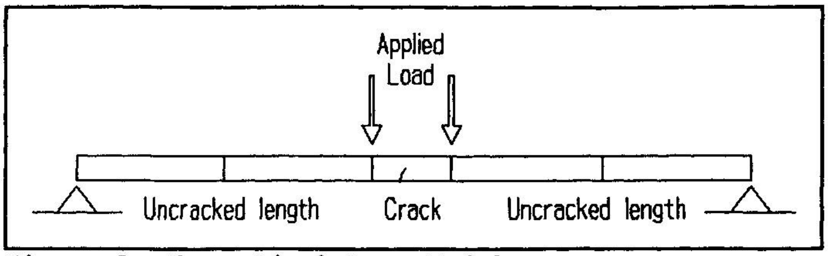

Figure 3: Theoretical Beam Model

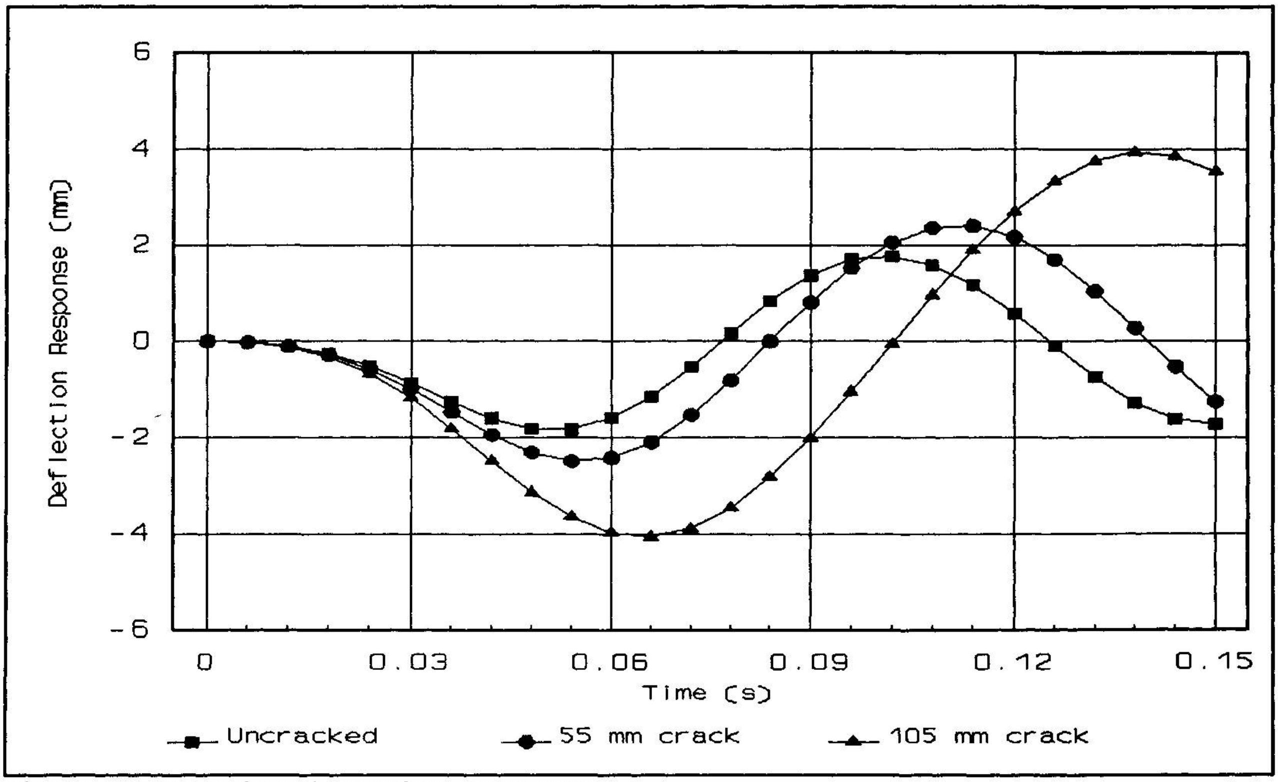

Figure 4: Calculated Impulse Responses

Two different loads are considered in this theoretical analysis:

- a load of 0,6 kN, at a frequency of 8 Hz. This assumed load is based on the work of Allen [3], which deals with loads generated by aerobics exercises, and assuming four people on the beam and the third harmonic.
- a triangular impulse load, to approximate a heel drop load, rising to a peak of 5 kN and dropping back to zero over a time period of 0,07 s. The calculated deflection vs time curves for this impulse load on the three beams, are shown in figure 4.

The results of these analyses are all listed in table 3.

4. DISCUSSION OF RESULTS

It is clear from the preceding measurements and analyses that cracking of concrete will alter the vibration amplitudes of the floor. This alteration in amplitudes results directly from the stiffness variations, and indirectly from the reduction

Load	Beam Condition	Natural Frequency Hz		Max. Disp. Response mm	
		2,38 m	5,00 m	2,38 m	5,00 m
0.6 kN at 8 Hz	Uncracked	45,4	10,3	0,018	0,429
	55 mm crack	35,0	8,9	0,034	1,231
	105 mm crack	23,4	6,7	0,088	1,131
Impulse	Uncracked	45,4	10,3	0,129	1,828
	55 mm crack	35,0	8,9	0,246	2,488
	105 mm crack	23,4	6,7	0,787	4,063

Table 3: Theoretical Results of Beam Vibration

in natural frequencies and mode shapes of the floor, which influence the manner in which the floor responds to applied dynamic loads.

Four factors emerge from this study. First, the stress fluctuations caused by the normal levels of vibration expected in a building are insufficient to cause cracking or extend existing cracks. An uncracked concrete beam thus behaves as if the full concrete section is active, resisting both compressive and tensile strains.

Second, the influence of cracks is to reduce the stiffness, thereby increasing static deflections and reducing the natural frequency. There is thus a compounding effect on the deflection, or acceleration, response to vibrations as lower natural frequencies usually result in higher dynamic amplification.

Third, the effect of prestressing is to override the influence of cracks if the general level is less than the prestress. This is shown in table 1, where it can be seen that neither the stiffness nor the natural frequencies of the prestressed beams are significantly by cracking when the general loads are low. The vibration characteristics of any form of prestressed concrete floor, are thus influenced by both the extent of cracking and the level of general loading on the floor.

Fourth, where vibration testing of floors is undertaken to establish acceptability in terms of some serviceability criteria, this testing should preferably be carried out once the floor is fully furnished and occupied. Should testing be done immediately on completion of floors, it is possible that the test results will record a rather different vibration response than may be evident at a later stage.

It is thus apparent that the vibration amplitude of cracked concrete floors may be significantly more than that of uncracked concrete floors, so it is recommended that dynamic design procedures should consider concrete floors to be cracked, even when the vibration stress amplitude is insufficient to cause cracking. This is particularly true in the case of lightly prestressed concrete floors, where the normal working stress levels may be sufficient to exceed the prestress.

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