Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 69 (1993)

Artikel: Role of load testing and structural monitoring in appraisal

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DOI: https://doi.org/10.5169/seals-52551

Role of Load Testing and Structural Monitoring in Appraisal

Rôle des essais de charge et étude structurelle lors des évaluations

Rolle der Belastungsprüfung und Tragwerksüberwachung bei der Bewertung

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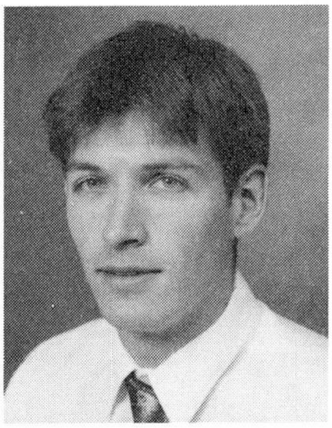

Richard Moss, born 1963, obtained his first degree at Sussex University and his Ph.D. from Imperial College, London University. During his period of 8 years at BRE, his research has concentrated on load testing although he has recently initiated research on structural monitoring and has carried out general appraisal work.

SUMMARY

This paper considers the role of load testing and structural monitoring in appraisal. Problems associated with each of these techniques are identified and possible solutions explored. Particular problems identified in relation to load testing are the interpretation of the results and practical difficulties of carrying out the tests. The author concentrates in particular on enhancement in stiffness produced by non-structural screeds, and results from a large programme of work testing beam and block concrete floors are discussed. In overcoming practical difficulties dynamic testing is put forward as a possible alternative to static load testing in certain circumstances. Problems associated with monitoring schemes are also considered.

RESUME

Le présent exposé examine le rôle des essais de charge et de l'étude structurelle lors des évaluations. Les problèmes normalement associés à chacune de ces techniques sont ici identifiés, et les éventuelles solutions explorées. Parmi les problèmes particuliers associés aux essais de charge, il faut mentionner l'interprétation des résultats et les difficultés de nature pratique, à savoir la réalisation proprement dite desdits essais. L'auteur met l'accent sur la rigidité produite par les revêtements, et examine les résultats d'un vaste programme d'essais de planchers en béton formés de parpaings ou de poutres. En vue de résoudre les difficultés pratiques, il est fait mention des essais dynamiques en tant qu'alternative possible aux essais de charge statique dans certaines situations. Par ailleurs, sont également abordés les problèmes associés aux projets de contrôle.

ZUSAMMENFASSUNG

Der Beitrag behandelt die Rolle der Belastungsprüfung und Überwachung bei der Tragwerksbewertung. Es werden mit diesen Verfahren verbundene Probleme herausgestellt und mögliche Lösungen gesucht, Ausdeutung der Ergebnisse und praktische Schwierigkeiten bei der Ausführung der Prüfung. Der Verfasser konzentriert sich besonders auf die Steifigkeitserhöhung, die sich aus nichttragenden Anstrichen ergibt, und diskutiert die Ergebnisse eines grossen Arbeitsprogramms, in dessen Rahmen Balken- und Massivbetondecken geprüft wurden. Zur Lösung der praktischen Schwierigkeiten wird unter gewissen Umständen eine dynamische Prüfung als Alternative zur statischen Belastungsprüfung vorgeschlagen. Mit der Überwachung verbundene Probleme werden ebenfalls behandelt.

1. INTRODUCTION

1.1 The average age and number of existing structures is increasing with time and structures, particularly concrete structures, are subject to deterioration mechanisms which can eventually result in impaired structural performance. In the future there will therefore be an increasing burden of maintenance and repair and an increase in demand for structural re-evaluation, central to which is the appraisal and assessment of structures.

1.2 The sources of information available to an engineer when carrying out an appraisal on an existing structure are:

a. Existing documentation on the original design and construction and any subsequent modifications.

b. The maintenance history of the structure.

c. Surveys of the structure providing information on:

1. As-built dimensions, reinforcement details etc.
2. Present loadings (from re-assessment of current dead and imposed loads).
3. The physical condition and properties of the construction materials.
4. Any visible defects.

2. THE RÔLE OF LOAD TESTING AND STRUCTURAL MONITORING IN APPRAISAL

2.1 Other techniques in addition to the above can be used, in particular load testing and structural monitoring.

2.2 Load testing involves the application of test loads to a structure and measurement and interpretation of the response of the structure to those loads. Full-scale load tests are normally very expensive and time-consuming to carry out. However, there are some structures which are not amenable to calculation and in such circumstances the only way to make an assessment is to carry out load tests.

2.3 Where there is a change of use of a structure or for some other reason there is doubt as to the structural adequacy of the construction, a subsequent approach to carrying our conventional structural assessment is to install a monitoring scheme. Structural monitoring is a developing field and there is a need to develop an understanding of what can be achieved by monitoring. Research is also required to develop the methodology and hardware systems for in-service monitoring of building structures.

2.4 Application of appropriate assessment and monitoring techniques can provide justification for extended building life with potentially very substantial cost savings.

3. PROBLEMS ASSOCIATED WITH LOAD TESTING

3.1 Interpretation of results

3.1.1 The main problem associated with load testing is interpretation of the results from tests since correct interpretation relies on a proper understanding of the behaviour of structures.

3.1.2 In his research the Author has addressed specific issues in relation to load testing of floor and roof structures [1]. The need for further research on load testing was identified in the light of the results of investigations into the use of high alumina cement concrete (HACC) construction [2]. HACC was used extensively to manufacture floor beams used in beam and pot type floor and roofing systems.

3.1.3 The particular problems addressed by the Author are the assessment of the effects of load distribution and, secondly, the assessment of the influence of movements resulting from temperature variations upon the load induced deformations.

3.1.4 To solve these problems the Author has developed methods using linear theory and heat conduction analysis leading to assessment of load distribution, thermal deflections and load corrections.

3.1.5 The Author has completed a large programme of work testing beam and block floors looking at the influence of different types of floor screed on the structural behaviour. This work has demonstrated the very considerable increase in stiffness due to non-structural screeds and this is described further in Section 4.

3.2 Practical and logistical difficulties

3.2.1 The other main problem associated with carrying out full-scale static load tests is the time, inconvenience and expense associated with them. In contrast to static testing, dynamic testing, although requiring specialist equipment and personnel, is much quicker and easier to carry out, and hence the possible role of dynamic testing in load testing procedures has been explored.

3.2.2 From the dynamic tests carried out attempt has been made to predict behaviour under static loads from measured dynamic characteristics. The results available so far suggest that a reasonable estimate of the extent of lateral load distribution can be made, but that the magnitude of the deflection is not predicted very well as illustrated in Figure 1.

3.2.3 Dynamic testing may have a potential role to play in selecting test areas and also assessing boundary conditions. However by its very nature dynamic testing can only provide an insight into behaviour at load levels generating a linear response.

4. ENHANCEMENTS IN STIFFNESS DUE TO NON-STRUCTURAL SCREEDS

4.1 Details of tests on beam and block floors

4.1.1 A large programme of testing of beam and block floors has been carried out, principally up to and slightly beyond service loads. This is so that at each stage of construction the load-deflection curves obtained were repeatable, and the additional stiffening effect produced by that stage of construction assessed. The stages at which the floor was tested were:-

1. Individual beams
2. Beams and blocks (ungrouted)
3. Beams and blocks (grouted)
4. Beams and blocks (grouted) plus floating screed finish
5. Beams and blocks (grouted) plus unbonded screed finish
6. Beams and blocks (grouted) plus bonded screed finish

4.1.2 The boundary conditions of the floor were varied, and lateral restraint to transverse movement of the floor was found to have some influence on the stiffening effect produced and its reliability.

4.1.3 Tests on 11 nominally identical precast concrete beams showed there to be considerable variability in stiffness between them (± 10%).

4.2 Enhancements in measured beam stiffness

4.2.1 The term beam stiffness is here used to refer to the ratio of the load carried by a beam (as measured by its end reactions) to its central deflection.

4.2.2 The stiffness of an individual beam tested in the grouted floor was increased by about 20% when the floor was restrained in the transverse direction, and about 10% when unrestrained.

4.2.3 For the floor with different screed types with transverse restraint, the average stiffness increases were 75%, 37% and 360% for the floating, unbonded and bonded screed respectively. For the floor without transverse restraint the corresponding values were 85%, 36% and 270%. These stiffness increases correspond to reductions in deflections of about 40%, 25% and 75% respectively. Not surprisingly the stiffness increase produced by the bonded screed is considerably greater than that for the unbonded and floating screeds and this is illustrated in Figure 2.

4.2.4 The differences in measured stiffness increases of the beams were reflected in calculations which showed that only a very small width of floating screed (14mm) needs to be acting compositely with a beam to produce the stiffness increase observed, whereas the width of bonded screed needed is 225mm. The beam spacing was 500mm.

4.2.5 The Author is currently developing a model for assessing the stiffness increase produced by different types of non-structural screed, taking account of slippage at the interface between the screed and the other components.

4.2.6 The stiffening effects described above need to be considered when interpreting the results of load tests.

4.3 Reliability of stiffness increases determined

4.3.1 The stiffness increase produced by a floating screed was found to be dependent on how well the screed was bedded down onto the rest of the floor structure, and this must raise doubts as to what extent the stiffening effect of a floating screed could be relied upon in practice.

4.3.2 When testing the floor with a bonded screed cracking occurred in the screed above one of the beams, reducing its stiffness. This most likely resulted from lack of ability of the screed to resist tensile stresses induced as a result of differential movement between the beams and shrinkage of the screed after being laid. The reliability of a bonded screed could perhaps be increased by incorporating a nominal mesh within the screed to help resist tensile stresses.

4.3.3 Such cracking would be more likely to occur for a beam and block floor than for some other types of floor construction (e.g. hollow plank), because of greater tendency for outwards horizontal movement. However tests to 1.25 x design service moment which have recently been conducted on a hollow plank floor assembly have revealed a similar effect.

4.3.4 The extent to which the stiffening effects can be relied upon will depend not just upon on how reliable the interaction mechanism is, but also on whether the physical presence of the screed can be guaranteed. In such cases there is clearly a need for redefinition of what can be classed as 'structural' and what is 'non-structural'. Enhancements to stiffness provided by different screed types could eventually be taken account of in the design process, although much greater attention would then need to be focused on the specification of the 'non-structural' materials.

5. PROBLEMS ASSOCIATED WITH STRUCTURAL MONITORING

5.1 The problems associated with monitoring schemes can be divided into four broad categories. These are:

a. Defining the objectives of the scheme

b. Selection of positions to monitor

c. Instrumentation and system performance

d. The limitations of monitoring systems in warning of sudden distress.

5.2 There are many reasons for installing a monitoring scheme but they can be broadly categorised as:

a. Where modifications to existing structures are being carried out (strengthening, demolition etc)

b. Where long-term movements are required to be monitored (eg due to ASR, temperature changes, ground movements etc)

c. Where structures are subject to ongoing corrosion damage or other forms of deterioration

d. For research purposes (ie to provide a direct feedback loop to the design process in terms of providing a better understanding of structural behaviour and the actions to which structures are subjected)

e. Where accurate assessment of fatigue life is required (eg for bridges and offshore structures)

f. Where a novel system of construction is being employed (eg use of alternative prestressing materials and spaceframes).

6. PROGRAMME OF RESEARCH ON STRUCTURAL MONITORING AT BRE

6.1 The programme of research currently in hand at BRE aims to tackle the problems identified above. Work is being carried out under contract which will help to develop a methodology for deploying monitoring instrumentation based on concepts of robustness and vulnerability.

6.2 Reviews of case histories of structural monitoring and instrumentation have been completed [3], [4] and small-scale trials of instrumentation are under way.

6.3 The review of instrumentation which has been carried out in parallel with the review of case histories has identified the parameters which it is desirable to measure, the most appropriate instrumentation to use for measuring these parameters, and the most appropriate data logging system in which to integrate the instrumentation.

6.4 The instrumentation which has been considered has in general been restricted to that which is capable of being incorporated within data logging systems so that measurements can be taken automatically and remotely. Such a system is essential where large numbers of instruments required to be read within a relatively short time span, or alarms are to be activated.

6.5 In the review future developments such as the use of expert systems and active structural control are also considered.

6.6 There is a potential rôle for expert systems in aiding the interpretation of data obtained from a monitoring scheme, and such information could ultimately be used to control the response of a structure, for example under earthquake or other extreme loading conditions.

6.7 Expert systems work on the premise that there is a considerable data bank of existing knowledge and expertise. In many cases this data bank will not be available for structural monitoring applications and in these circumstances the expert system would need to be developed over a considerable period of time based on experience with the particular structure concerned.

6.8 In his review the author concludes that it is not practicable to formulate practical instrumentation systems for different applications. Rather the approach he suggests is to have a 'tool-kit' of available instrumentation from which to choose the best instrumentation for any particular application.

6.9 Recommendations are given on the most promising instrumentation devices to form part of this 'tool-kit' and the most suitable data logging system in which to integrate them. These recommendations have formed the basis for the small-scale trials currently in hand.

6.10 For long-term monitoring (ie over many years) the reliability and stability of the instrumentation is of crucial importance and one of the main objectives of the small-scale trials is thus to test out the long-term performance of different types of instrumentation.

7. CONCLUSIONS

1. Attempts at predicting static behaviour from measured dynamic characteristics have met with some success. A reasonable estimate of the extent of lateral load distribution could be made, but the magnitude of the deflections was not predicted very well.

2. Dynamic testing may have a rôle to play in selecting test areas and assessing boundary conditions. However by its very nature it can only provide an insight into behaviour at load levels generating a linear response.

3. For beam and block floors non-structural screeds, particularly bonded screeds, laid over the top surface will have a very considerable stiffening effect.

4. The reliability of the stiffness enhancement will vary between different types of screed, and the enhancement produced by floating and bonded screeds may be less reliable than for unbonded screeds.

5. Enhancements in stiffness produced by non-structural screeds need to be taken account of when

assessing the performance of existing floor construction. Such enhancements might eventually be taken account of in the design process, although much greater attention would then need to be focused on the specification of the 'non-structural' materials.

8. ACKNOWLEDGEMENTS

The author would like to acknowledge the assistance of Mr D Brooke in testing of the beam and block floors with unbonded and bonded screeds, and in the preparation of the figures.

9. REFERENCES

1. MOSS R.M. Load Testing of Floors and Roofs. The Structural Engineer, Vol 69, No 19, October 1991.
2. BATE S.C.C. High Alumina Cement Concrete in Existing Building Superstructures. BRE Report, HMSO, London, 1984.
3. MOSS R.M. A Review of Case Histories of In-Service Structural Monitoring (Private Communication).
4. MOSS R.M. A Review of Instrumentation for In-Service Structural Monitoring (Private Communication).

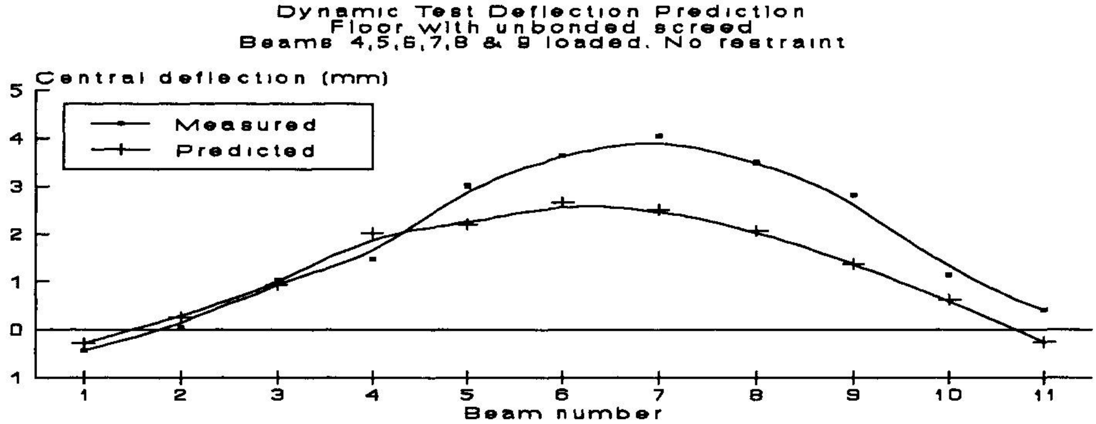

Figure 1: Comparison of measured deflections and deflections predicted from dynamic analysis for beam and block floor with unbonded screed.

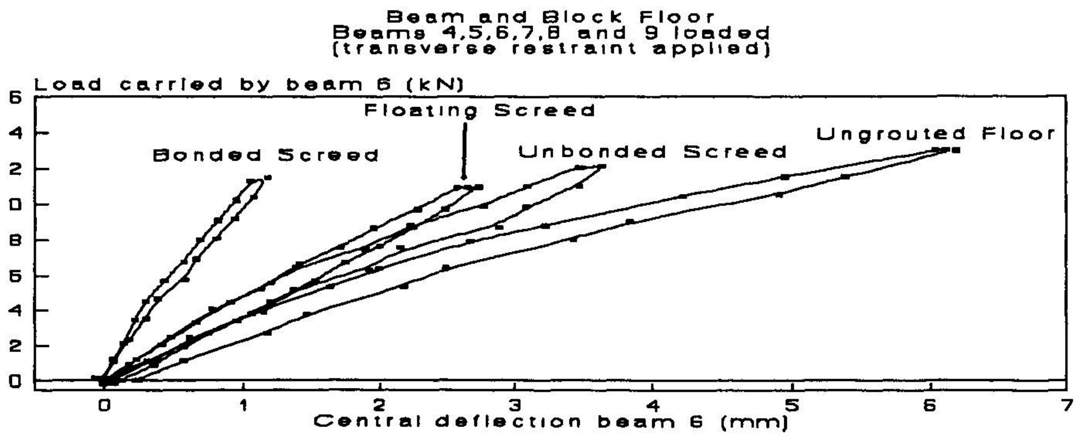

Figure 2: Influence of screed type on beam stiffness. (Transverse restraint applied)