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Deflection Prediction of Reinforced Concrete Structures

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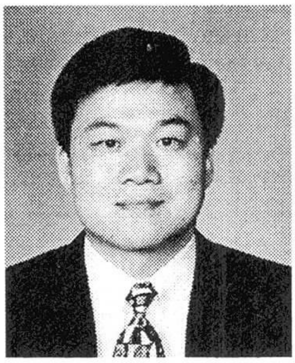

Abstract

The serviceability design criteria for tall structural concrete buildings is to restrict the level of movement due to lateral loading so that it is acceptable to the occupants and the general functioning for the intended purpose of the structure. Current code guidelines give various values, based both on analytical and experimental results, to determine the ***EI*** of the structural members for use in sidesway calculations. To improve the prediction of lateral deflection, and hence optimise structural size and layout, a more accurate method to predict the effective stiffness of components and sub-assemblages, which accounts for the factors which influence the structural response, is required.

The factors that influence the overall response of reinforced concrete structures can be categorised into three classes, external causes, internal causes and effects. The external causes include loading types and boundary conditions, the internal causes involve material and section properties, and the effects include various cracking patterns and tension stiffening. The philosophy in solving for the cracking effects is that it is a result of the interaction both the external and internal causes.

To make this improvement in evaluating the effective stiffness, a method has been developed based on the above philosophy and the probability of crack formation in reinforced concrete components. The most significant feature of the proposed model is its extensive applicability to the members subjected to various loading types. This method considers the ratio of the area of the moment diagram segment of a member in which the working moment exceeds the cracking moment, to the total area of the moment diagram. The probability of the occurrence of cracking is then used to calculate the effective stiffness of the structural component at member level. The stiffness of each component can be combined to produce the overall stiffness of the structure under given loading conditions. A design orientated analysis system has been established by integrating the proposed stiffness reduction model, iterative algorithms and commercial packages of linear finite element analysis. This model forms part of a design orientated integrated analysis system to quantitatively account for the cracking effects on the lateral deflection and stiffness characteristics of tall reinforced concrete buildings with loading in the serviceability range.

A comprehensive comparison with available test data as well as an experimental test program, to determine the accuracy and limitations of the above method, has been conducted. The experimental program comprised the testing of beams and a large-scale frame incorporating these structural components. The structural response of the flexural beams, and frame test incorporating beams and columns, are reported in this paper.

Nine reinforced concrete beams with dimensions of 300mm x 450mm and 3m clear span and with varying reinforcement ratios, were subjected to midspan concentrated loading, two-point concentrated loading and uniformly distributed loading. The two-storey reinforced concrete test frame had a center-to-center span of 3000 mm and an inter-storey height of 2000 mm. The beams of the frame had dimensions of 250 mm by 375 mm deep and columns with dimensions of 250 mm by 375 mm. Sidesway testing of the frame involved the application of lateral loads at the level of the second floor beam. A vertical load of 200 kN was applied at the top of each column to simulate gravity load through the structure.

From the available published data, and from the test series forming part of this work, the probability based analytical model provides improved accuracy over conventional methods for the prediction of effective stiffness of flexural reinforced concrete members under service loads. The model has been integrated into a linear finite element package to account for cracking and an iterative procedure presented to calculate the nonlinear lateral deflection of reinforced concrete structures with cracking under service load. The procedure can be used to calculate the load-deflection history as well as calculate the deflection under any desired working load stage.

In the serviceability range, the flexural stiffness reduction due to cracking is a dominant component resulting in the nonlinear load-deformation response of reinforced concrete structures. The analytical results and experimental observations indicate that the cracks occurring in the beams are responsible for the first abrupt reduction in overall lateral stiffness at a low load level, approximately 15% of ultimate load. The stiffness of beams generally reduce to around 50% of the gross moment of inertia at 50% ultimate lateral load, with further reduction as the lateral load reaches 70% of ultimate.

The proposed method is a valuable tool in the design of tall structural concrete buildings.

FRP Reinforcement for Concrete Structures : State-of-the-Art

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Summary

Several types of FRP (fibre reinforced polymers) reinforcement have been developed in recent years. These elements are not susceptible to the usual types of corrosion. The paper gives a survey of the main characteristics of FRP reinforcement and shows some of the applications.

Keywords: Fibre Reinforced Polymers, FRP reinforcement, concrete, state-of-the-art

1. Introduction

If properly designed, constructed and maintained, reinforced or prestressed concrete structures generally have service lives of 50 years and more. Nevertheless, durability problems often occur, among which corrosion of steel, especially for concrete structures in aggressive environments. Hence, there is an increasing interest in the use of non-metallic reinforcement which is not susceptible to the classical types of corrosion. Recent evolutions in the field of material engineering offer new possibilities, such as the use of advanced composites or "fibre reinforced polymers". These so-called FRP reinforcements can serve as a viable alternative to reinforcing and prestressing steel, as has been demonstrated by several research and demonstration projects.

2. Materials

As structural reinforcement for concrete members, FRP elements are made available in the form of bars, tendons, ropes, grids, sheets or profiles. For new structures, they are used to reinforce and prestress concrete elements. In the repair sector, they are used to strengthen existing structures e.g. by means of external post-tensioning, external sheet bonding or in combination with shotcrete. The tensile stress-strain behaviour of FRP made of aramid, carbon and glass fibre (AFRP, CFRP and GFRP) as compared to reinforcing and prestressing steel are shown in figure 1. Similar to the behaviour of the fibres and unlike steel, FRP do not experience any yield but rather a linear elastic

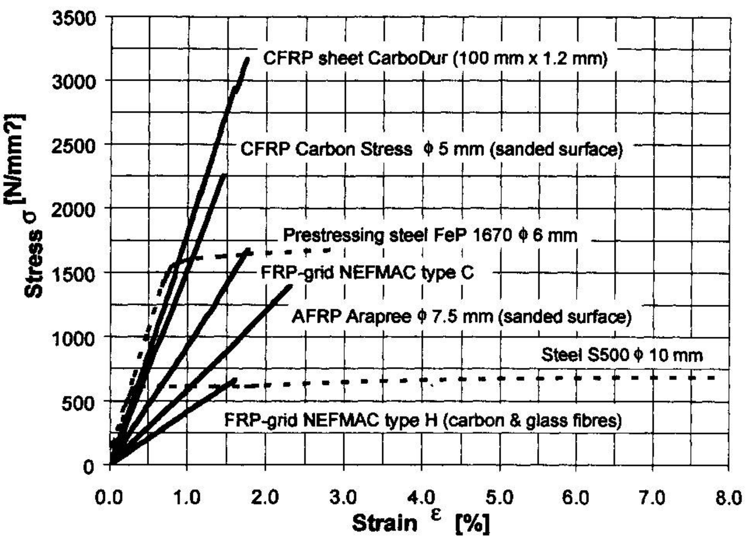

Fig. 1. Stress-strain curves of FRP elements

behaviour nearly up to failure. Compared to steel, the Young's modulus for FRP is often much less and ranges between 50 to 250 GPa, while the tensile strength is close to that of prestressing steel. The mechanical properties of aligned composite materials transverse to the fibres are much less than those parallel to the fibres.

3. State-of-the-Art Overview

When FRP is used for reinforced concrete (RC), the low modulus of elasticity results in large deformations. This makes FRP (from a structural point of view) more suitable for prestressed concrete (PC). Nevertheless, a number of projects with FRP RC members have been completed. Concerning pre- and post-tensioning with FRP, several applications are available in Japan, Europe and North-America.

Whereas, the application of structural FRP reinforcement for RC and PC members basically concerns demonstration projects so far, the use of externally bonded FRP reinforcement is growing commercially in a fast way. With this strengthening technique both advanced properties and ease-of-application are offered.

4. Design Guidelines

The considerable interest in FRP as structural reinforcement will only successfully result in applications on a broader basis, if design guidance and finally code regulations are available. In Japan, the U.S.A., Canada and Europe several initiatives have been. A fib (International Concrete Federation) Task Group "FRP Reinforcement", convened by the first author, is elaborating design recommendations based on the design format of the CEB-FIP Model Code and Eurocode 2.

5. Conclusions

FRP reinforcement may offer a practical and economical alternative to conventional steel reinforcement. It must be appreciated that the application of FRP reinforcement is partly in an experimental stage and that different aspects of this new technology will be the subject of more detailed investigations. Nevertheless, several initiative to establish design guidelines have been taken as a result of the considerable interest in this novel reinforcing material.

The application of FRP reinforcement is related to the utilisation of the specific material properties of FRP. Therefore, it has to be used as a specific alternative for common steel reinforcement, rather than a general substitute for it.

Chloride Ingress in Blast Furnace Slag Cement in Marine Concrete Structures

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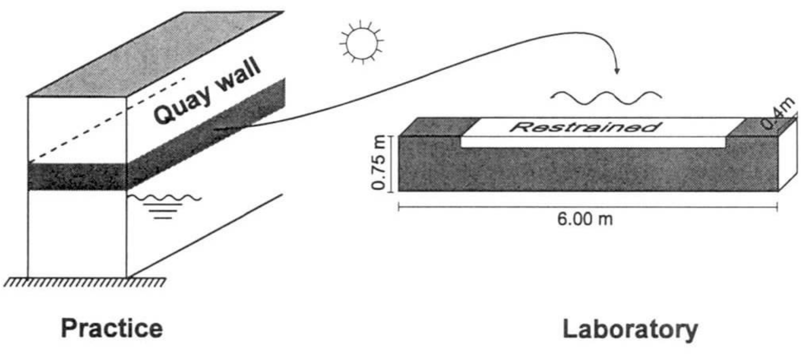
Abstract

Numerous reports about unsatisfactory performance of reinforced concrete structures subjected to marine environment reveals that the existing design codes and recommendations do not always adequately meet the real requirements for long term durability of such structures. The interaction between the materials and structure as a whole on the one hand and the climatic conditions to which the structure is exposed on the other hand, is a key point to be considered in any durability assessment of marine reinforced concrete structures. Splash/tidal zone of marine structures is the most critical part of these structures in terms of susceptibility to damage due to chloride-induced corrosion of reinforcement. In the parts of the structures subjected to alternate wetting and drying the chloride ions move into concrete relatively fast. Furthermore, in concrete members, temperature and shrinkage may introduce deformations. When such deformations are restrained, stresses will occur. So, the dominant cause of unanticipated cracks in concrete elements is the natural restraint of deformations in concrete structures.

In an experimental study, performance of different concretes exposed to a simulated marine environment is investigated. The severe marine conditions were simulated by alternating drying/wetting with salt water and heating/cooling cycles. One of the key points in this investigation is that chloride penetration is studied in full-scale concrete elements of which deformations, caused by temperature and drying and wetting, are naturally restrained (see Fig.). The (micro-) cracks induced by thermal stresses may increase the permeability and promote chloride ingress into concrete.



"Presentation of practice oriented full scale experimental research and the restrained temperature induced deformations at the top of the beam"

Variables in this study are the level of restraint in specimens, temperature, cement type and curing conditions. All concrete specimens, including large beams and small cubes, are subjected to alternate wetting and drying cycles to simulate the marine condition. In addition, temperature variations are applied to some specimens. In total 90 complete exposure cycles of wetting and drying plus heating and cooling are applied to large beams (from one side) and to small cubes. The applied exposure condition consists of a drying period of 42 hrs followed by a wetting phase of 6 hrs with salt water containing 5% NaCl. The drying phase is a thermal regime characterized by a temperature swing from 20 °C to 60 °C within a period of 12 hrs. This simulates, with some acceleration, the aggressive marine environment in hot regions with varying daily temperature including direct solar radiation.

Two types of concretes, one with ordinary Portland cement and one blended with 70% blast furnace slag cement, cured with different conditions, are used in this experiment. Two curing regimes, i.e. standard curing and elevated temperature curing, are imposed upon the specimens. In standard curing, the specimens were exposed to room temperature and humidity, for 14 days. In the case of elevated temperature curing, concrete beams and cubes were exposed to the controlled environment with a temperature of 38 °C and relative humidity of 50%, also for 14 days, to simulate the curing conditions in tropical regions.

Observations after one month and six months of exposure showed that no significant microcracks had occurred at the surface of the concrete beams. Comparison of the chloride measurements in large elements and small specimens, both exposed to temperature and hygral variations, showed that (non-intensive) microcracks at the surface layers due to restraint of temperature-induced deformations, did not promote chloride penetration rate in the large specimens noticeably. The effect of microcracking, induced by temperature variations, on the rate of chloride penetration seems to be less than what has been suggested in the literature, at least with this particular test and boundary conditions. The pronounced effect of temperature cycles, however, was found to be more through the pore structures of the concrete than through the minor microcracks.

Slag cement concrete performed better than Portland cement concrete in the simulated aggressive marine environment. Furthermore, the elevated temperature curing had a substantial effect on promoting the chloride transport in concrete with Portland cement. In slag concrete, however, the elevated temperature curing did not show increase in ingress rate.

Regarding the numerical simulation, with *time dependent* values of the chloride diffusion coefficient and surface chloride content it was found that the error function solution to Fick's second law of diffusion can, with sufficient confidence, be used for non-steady state situations, such as the simulated marine condition in the performed experiment.

In the paper the focus is only made on the beneficial use of Portland cement blended with the slag cement and the satisfactory performance of slag concrete in comparison with concrete made with only Portland cement is highlighted. The "achieved chloride diffusion coefficients" for some of the specimens of both concrete types are also presented and compared. The effect of other parameters, mentioned above, has been discussed in other papers which are referred in this paper.

The results of this investigation, in the light of the experimental and numerical simulation, contribute to conclude that when designing any structure which will be exposed to sea water, unblended Portland cement concrete can not be expected to protect the steel for long term. Many other authors on the basis of site investigations have made the similar finding on performance of marine structures made with slag cement concrete with lower w/b ratio. The results confirm that tropical marine environment provides more aggressive conditions to the concrete and enhances the deterioration rate and hence shortens the service life of structures. Ground granulated blast furnace slag concrete (or concrete with other supplementary materials, like silica fume) should always be used in such an environment.

Amount of Prestressing Based on Serviceability Requirements

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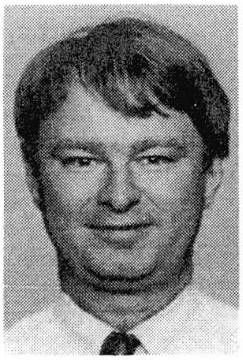

Olivier Burdet, born 1960, is a lecturer in reinforced and prestressed concrete. His research interests include serviceability, bridge design and monitoring techniques.
He is a member of the Publications Committee of IABSE SEI Journal.

Summary
The paper proposes design criteria for the choice of the amount of prestressing. Based on an extension of the well known load balancing method, the proposed criteria permit a simple and effective design of the amount of prestressing at serviceability. The paper also discusses the favorable effect of compressive stresses induced by prestressing on cracking and water-tightness of PC structures. In situ measurements as well as numerous test results demonstrate that the proposed criteria lead to structures that are more durable and less prone to an increase in deflections and cracking over time.

Keywords: bridges, prestressed concrete, serviceability, cracking, design criteria, cyclic loading, in situ measurements, residual crack opening, water-tightness

Abstract

Behavior in service is extremely important for all structures, and serviceability requirements should be central in the choice of the amount of prestressing. They are unfortunately often omitted in the initial design, only to be checked in subsequent verifications. This is unfortunate, considering the fact that structures spend most of their useful life at the serviceability limit state. Owners and users alike are more concerned with the actual behavior of structures during their service life than by their possible behavior at the ultimate limit state.

In spite of intense research in the field of cracking and deformations, there is a lack of clear and easily applicable design procedures for the serviceability limit state,. This article proposes such criteria, based on the concept of compensation of deformations, which is essentially a generalization of the load balancing method. These criteria are essentially based on the behavior under permanent loads. The paper, however, includes some considerations about irreversible effects due to cracking under variable loads.

In the **compensation of deformations** approach, instead of *balancing loads* as in the load balancing method, the designer *compensates deformations*. Although it increases the computing effort, this approach has the great advantage of taking into account the effect of anchorage forces and the effect of non-rectilinear gravity axes (fig. 1). The degree of compensation of deformations β is defined as :

$$\beta = \frac{w_c\,(P_m)}{w_c\,(g)} \quad with \quad P_m = \frac{P_{t=0} + P_{t=\infty}}{2}$$

where

w_c : elastic deflection at mid-span (creep is not taken into account as it would appear in the numerator as well as in the denominator of eq. 1)

P_m : average prestressing force over the lifetime of the structure , $P_m = (P_o + P_\infty) / 2$

β : degree of compensation of defections

g : permanent and occasionally semi-permanent loads

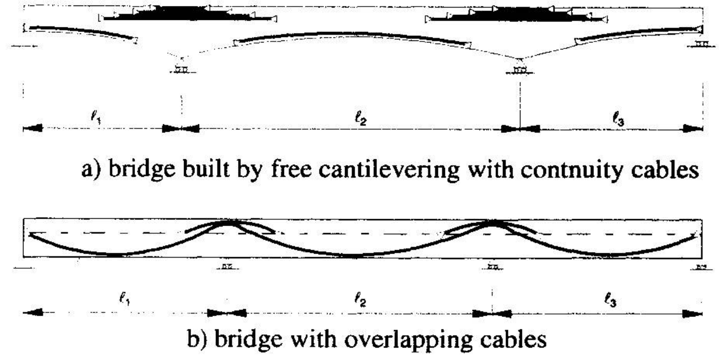

Figure 1: Situations for which the application of the load balancing method is impractical

Because moments induced by the prestressing cables only approximate the moment diagram induced by permanent loads, the value of β defined above varies slightly from point to point along the axis of the structure. For simplicity's sake, β is normally taken at mid-span

Table 1: Recommended β-values for various types of structures

Type of structure	Increased requirements	Normal requirements
Road bridge	0.9	0.8
Rail bridge	1.1	1.0
Building slab	0.6	0.5
Heavily loaded slab	> 0.6	> 0.5

The concept of compensation of deformations permits a **choice of the amount of prestressing** based on a single global and rational criterion. Table 1 gives values of β as a function of the structural type and requirements. These values are indicative, in that they are to be used for the initial choice of the amount of prestressing, and that they are not intended to replace the usual code checks. As a rule, the amount of prestressing obtained by applying this table is slightly larger than the minimum amount required by most current codes. The values given for slabs are smaller than for beams, because of the favorable effect of the tensile strength of concrete. Observed behavior both short- and long-term demonstrate that the proposed values lead to an excellent performance in service. At the same time, it has been observed that bridges with β-values significantly lower than indicated in table 1 often exhibit an unsatisfactory behavior at service state.

Table 2: Residual crack opening after an exceptional loading

σ_{perm} [MPa]	≈ 0	-0.5	-1	-2	≤ -5
w_{res} [mm]	0.2	0.1	0.075	0.05	0.025

A good behavior in service implies that cracks that may occasionally open under exceptional service loads have a sufficiently **small residual crack opening** under permanent loads. Passive reinforcement ratio, bar diameter and concrete properties have a strong influence on residual crack opening, but the two most important factors are the stress level under permanent loads and the magnitude of the maximal tensile stress under the exceptional load. Table 2 summarizes the results of a parametric study for typical stress ranges. It indicates the compressive stress required to effectively limit the residual crack opening under permanent loads w_{res}. Its validity is limited to the case when no yielding of the reinforcement occurs under the exceptional load.

Conclusions

Starting from a perspective of good behavior at the serviceability limit state, the article proposes **very general criteria** for the choice of the amount of prestressing. These criteria are focusing on the behavior under permanent loads for both cracking and deflections. The influence of variable actions (movable loads and temperature) is taken into account through their irreversible contribution to the behavior under permanent loads.

Vibration Performance of Footbridges Established via Modal Testing

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Abstract

Modal testing techniques are increasingly used to obtain the dynamic properties of civil engineering structures for the subsequent calibration of the finite element (FE) models used for their design. This makes it possible to improve future analyses of the vibration performance of such structures. These coupled experimental and analytical FE model updating techniques, which have developed rapidly in the 1990s, originated in the mechanical and aerospace engineering disciplines. They have been applied successfully to the dynamic testing of medium sized full-scale structures, such as long-span floors, footbridges and chimneys, as well as to larger structures such as suspension and cable-stayed bridges.

A footbridge may experience disturbing vibrations while in use, and the aim of this paper is to investigate the effects of its layout and handrails on the natural frequencies, determined to be the sole most important factor which governs the vibration serviceability of the footbridge. The investigation is based on modifications to FE models calibrated against site tests of two prototype footbridges which could be considered as potentially lively.

The two footbridges tested were both single-span structures, the first a composite steel-concrete pre-cambered beam, and the second a single span stressed ribbon structure.

The first footbridge consisted of a 2.16 m wide concrete deck connected to a 0.225 m deep pre-cambered steel box girder. The structure had a span of 19.90 m and was supported on a pair of elastomeric bearings at each end. All four bearings were different and it was expected that they had different relative stiffnesses in the vertical and horizontal directions. Steel handrails, in the form of short independent panels made of hollow section components, were attached to the deck and followed its vertical profile.

The stress-ribbon footbridge consisted of a 34 m long by 1.8 m wide single span catenary shaped prestressed concrete slab which was fixed at the abutments. Steel handrails made of continuous hollow box sections were firmly attached to the slab. The depth of the deck was 160 mm thickened locally towards the ends. An asphalt topping of 12.5 mm constant thickness was placed on the top of the slab.

The two test structures were used to investigate potential improvements in their vibration performance. Attention was focused on the investigation of the natural frequencies caused by changes in the design and modelling of the structural layout and its components. This could be useful as a design strategy when performing frequency tuning exercises, frequently required when designing footbridges so that the critical frequency ranges of the excitation may be avoided.

In the case of the pre-cambered footbridge, modal testing carried out with and without handrails attached to the structure demonstrated only a small influence on the dynamic properties of the structure. The fact that the handrails were made of short independent panels eliminated any

stiffening potential, which is one of the ways of promoting frequency tuning.

The role of the elastomeric bearings in affecting the fundamental frequency of vibration was also investigated parametrically. The camber of the structure may induce some stiffening arching action, provided that there is a sufficient restraint to horizontal displacement at the elastomeric bearings. The predominant stiffening influence of the arching action is on the fundamental mode. This can be understood by the shape of this mode, implying that there are larger horizontal displacements, and consequently the mobilisation of the axial stiffening since these displacements are restricted to some degree by the bearings. The conclusion was that the use of the horizontal (i.e. shear) stiffness of the bearings, in association with a pre-camber may be an effective tool for changing the natural frequencies of pre-cambered footbridges.

In the case of the stressed ribbon footbridge, the handrails had a more significant influence on the vibration characteristics of the structure. Since the handrails were continuous, followed the catenary shape of the deck and were firmly attached to it, they contributed to both bending and axial stiffness of the structure. Both the deck and the handrails were modelled using rigidly connected beam elements. Indeed, an initial attempt to model the structure by including the handrails simply as an added mass resulted in a poor correlation between the experimental and FE results for some of the modes.

In order to investigate in more detail the role of the catenary shape on the modal properties, an FE model of the footbridge was prepared as if it were rectilinear. This resulted in a complete change of the modes of vibration, which were then similar to those of a straight beam, as expected. The first mode presented a natural frequency of 0.9 Hz and was symmetric, as opposed to the first anti-symmetric mode of 2.3 Hz measured on the actual footbridge. The difference in value between these fundamental frequencies shows the considerable effectiveness of a catenary shape in increasing the natural frequencies of footbridges.

The main conclusions from the experimental results and numerical exercises carried out were:

- A good representation of the dynamic behaviour of the stressed-ribbon structure was obtained by modelling continuous handrails as a frame rigidly attached to the deck. In the two test cases, an increase of up to 20% in the fundamental frequency was obtained when the contribution of the continuous handrails was taken into account.

- The best results in terms of frequency tuning were obtained by changes to the layout of the structures. A combination of a cambered or catenary profile together with horizontal restraint was shown to be useful for increasing natural frequencies, since it induces some stiffening by arching action.

Performance Based Seismic Design for Bridges

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Abstract

Performance criteria have been implemented by public works owners that require bridges to remain standing, and to be without significant damage following severe ground shaking. Based on project experience in California and other parts of the U.S., this paper will discuss the resulting design philosophy often referred to as performance based design.

This design philosophy can be applied to three key types of seismic design:

1. Identification of level of damage and collapse mechanisms
2. Designing for limited or no damage under the "design life" earthquake (250 - 300 year return period).
3. Designing for no collapse, limited damage, or no damage under the maximum credible earthquake (2000 - 3000 year return period).

This design philosophy has been developed into design production tools intended to predict levels of damage and to establish behavioural envelope for structures where the expected performance was established as "no collapse" by the design criteria. Key areas of discussion related to both concrete and steel bridges include:

1. Design using displacement based analysis.
2. Methodology for Performance Based Design
3. Design of new structures to meet serviceable performance criteria under design seismic events.

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Active Control for the Operational Safety of Control-Towers

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Summary

Operator's comfort in control towers can be troubled by the oscillations induced by winds and moderate earthquakes with consequences on the safety of the air traffic. An active control system, inserted at the top of the tower, can reduce the movements. Results of numerical simulations carried out on a sample tower, show that the effects of wind induced motion can be lowered below the satisfactory threshold and, when moderate earthquakes act, the response remain under the tolerability limit.

Keywords: Active and hybrid control; operator comfort; operational safety; wind; earthquake.

1. Abstract

The typical structural scheme of control towers (inverse pendulum) make them very sensitive to lateral dynamic actions. Depending on the frequency content and the acceleration values, induced lateral oscillations can trouble the operators jeopardising the appropriate progress of operations with risk for the air traffic safety.

Wind induced oscillations usually go on for a long time provoking discomfort and loss of attention. Short motions, like earthquakes of moderate intensity, not damaging structures nor endangering human life, can induce anxiety, fright, or even panic. Human perception of motion depends on acceleration, for short duration motions, and on acceleration variation, for a long excitation. The reduction of those response parameters limits perception.

ENAV (Ente Nazionale Assistenza al Volo), the Italian authority supervising the air traffic, pointed out the problem of providing a proper security to tower operators when lateral oscillations occur. The use of active control systems, already tested or installed on high buildings, was suggested for the high efficiency in reducing the response of systems characterised by a dominant frequency. Numerical simulations of the effect of a hybrid control system installed at the top of a typical control tower, aiming at reducing or eliminating the discomfort, have been carried out.

A typical configuration, reported in Figure 1, was suggested by ENAV to simulate the behaviour of a tower equipped with a hybrid control system. The mass values resulting from the load analysis are: 509 t for the service block, 350 t for the control block and 26 t/m for the column. The fundamental tower frequency results 0.606 Hz. A hybrid control device, shown in Figure 2, is located at the top of the tower. The system consists of a mass (92.6 t) sliding long two normal directions, tuned (0.57 Hz) to the fundamental frequency of the structure. Forces can be applied through a couple of actuators controlled by a controller. Steel springs and viscous oleo-dynamic dampers allow the suitable values of damping (92 kN·s/m) and stiffness (1187 kN/m) for the system. Sensors provide information on the input excitation and the structure response used by the controller to modify the response on the basis of the pre-defined set-point. The main characteristics of the hydraulic plant, resulting from the numerical computations, are: effective power = 160 kW, supply pressure = 315 bar, nominal delivery capacity = 360 l/min, accumulator capacity = 1000 l (enough for 30 s of supply).

The control system is designed to function according to the linear quadratic optimum control algorithm. Numerical simulations are carried out on a 2 DOF system. Lateral actions are simulated through four artificially generated time histories of both wind speed (duration = 600 s, average speed = 35 m/s, maximum speed = 50 m/s, Simiu's power spectral density) and ground acceleration (duration = 25 s, PGA=0.5 m/s^2, Eurocode response spectrum).

Results show that the r.m.s. of the response acceleration under wind excitation can be maintained under the satisfactory limit for buildings, avoiding discomfort. The average value of the r.m.s. of the response acceleration to the four considered wind speed histories without control is 0.16 m/s^2, this value is at the limit tolerated for an off-shore platform but eight times greater than the building limit. 0.03 m/s^2 is the value, below the satisfactory threshold, obtained with active control. If the device performs in passive mode its effect is reduced but still effective: 0.059 m/s^2.

Panic states can be avoided, when moderate earthquakes occur. The hybrid control system reduces the maximum value of the response acceleration from 1.03 m/s^2, which is intolerable, to 0.46 m/s^2, below the annoying limit. It is requested a higher power than in the case of wind.

The performances are provided by a system characterised by values of mass, forces, power, which can be supplied by normal equipment.

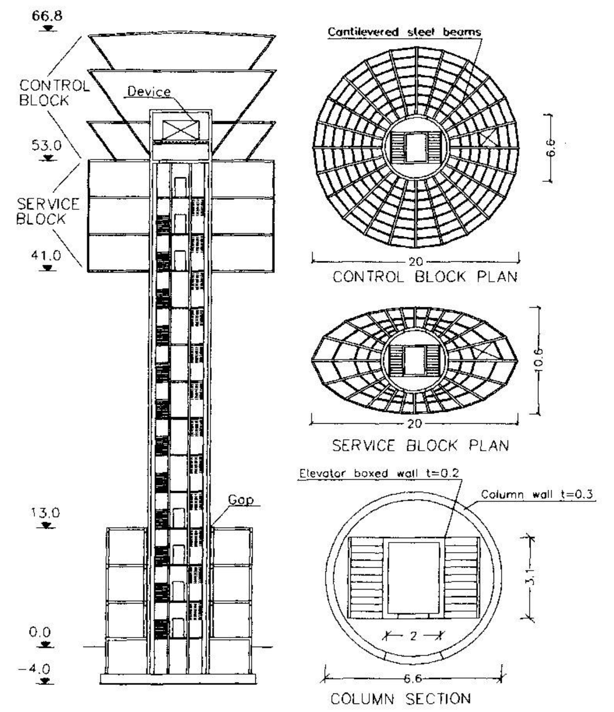

Fig. 1 – Sample tower

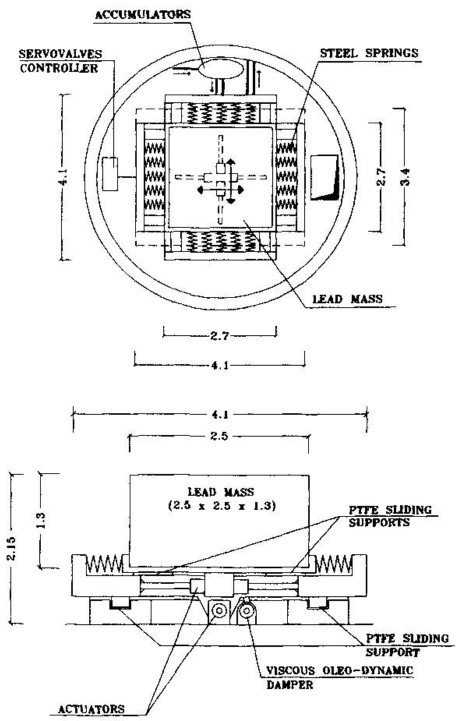

Fig. 2 Control device

Fatigue Tests for Predicting the Serviceability of Composite Bridges

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Summary

This paper abstract presents a part of a Ph.D. work on the fatigue behaviour of cracked RC slabs. It aims at verifying the fatigue resistance of slabs cast in situ and presenting cracks due to restrained shrinkage, as is the case of many composite bridges. The paper mainly treats the influence of cracks on the general behaviour of slabs, on stress distribution in steel bars after failure and on shear transfer mechanisms near through-going cracks. The experiments performed and the results are presented on 6 slabs constitute a major part of this study.

Keywords: Fatigue – reinforced concrete – slabs – tests – crack – serviceability – restrained shrinkage - composite bridges.

1. Introduction

This paper presents the ongoing research of a Ph.D. thesis at the "Ecole Nationale des Ponts et Chaussées" sponsored by Jean Müller International representing ASFA (French highway agencies association), the French road administration, the French Railway Company (SNCF), and the LCPC. Transverse cracks were observed on a significant number of composite bridge slabs. These through-going cracks appear at an early age with low concrete strength and considerable shrinkage. The connections between the steel girders and the concrete slab create tensile stresses exceeding the concrete strength. This study deals with inflection point zones where the shear forces due to heavy traffic are high. In these area the crack spacing variation is 0.25-0.50 m. The crack width were often 0 to 0.3 mm and sometimes 0.5-0.6 mm. A test program was established to acquire data regarding the influence of transverse cracks on the behaviour of slabs. Six RC slabs were tested to estimate the fatigue safety margin and the shear transfer degradation mechanisms: aggregate interlock, dowel action, fatigue of steel bars near transverse cracks.

2. Test presentation.

The experimental program included tests on six 5000x2900x180 mm RC slabs. The slabs were simply supported on two steel beams 4500 mm in length. The transverse and longitudinal steel bar ratios were respectively 1.2% and 0.6% of the concrete section. The characteristic strength of this concrete is 35 MPa. The initial state of damage is obtained by a tensile test conducted seven days after concrete is casting. This test allows the control of the crack width. Four parallel jacks

applied a uniform tensile. Longitudinal rigidity of the slab was deduced from LVDT sensors. The widths required were 0.5 mm for the first five slabs and 0.3 mm for the sixth. At the end of the test, when the steel bars were plasticised, the cracks had variable width and a 150-300 mm spacing. The consecutive load cycles reduce the longitudinal rigidity to the steel bars. The position and the spaces between the cracks were influenced by the presence of the steel bars.
A dynamique jack, shown in figure 1 applied the fatigue load. The load is concentrated on a steel plate between two major cracks. A the cyclic load representative of heavy traffic was applied on the first two slabs, varied from 10 kN to 86 kN. This load was repeated 10 million times representing one hundred years of heavy traffic on a French Highway. A S-N curve is used and helped to reduce the number of cycles by increasing the fatigue load.

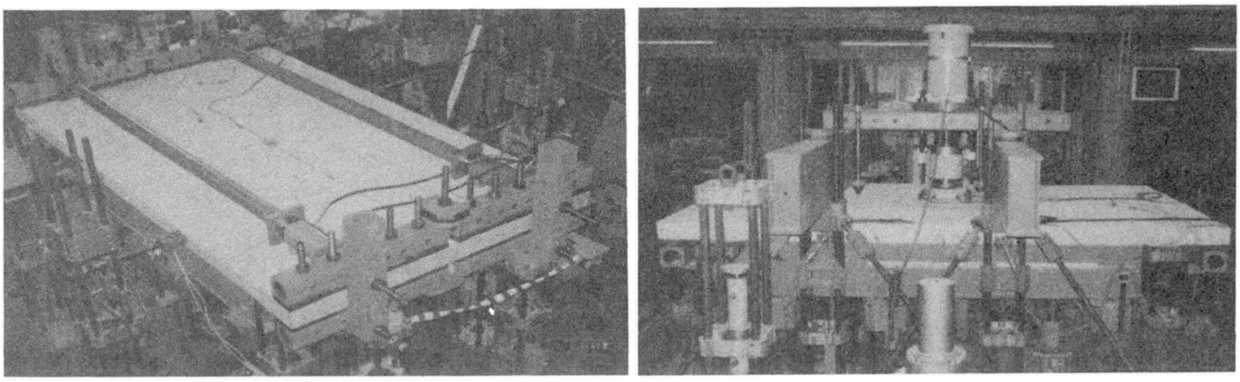

Fig 1: Illustration of tensile and fatigue tests.

3. Results and discussion

For the last slabs the fatigue load was increased up to 160 kN and 200 kN to show failures. No fatigue of shear transfer mechanisms was observed. Flexure is the fatigue failure mode. Figure 2 shows the influence of two steel bar failure on the displacement in the middle of the slab. The failures appeared only in the transverse bars in the middle of the slab. A static test was performed at the end of the fatigue test of the slab 2 and 5. Under static load, the shear load is critical. In the paper the results are commented and discussed.

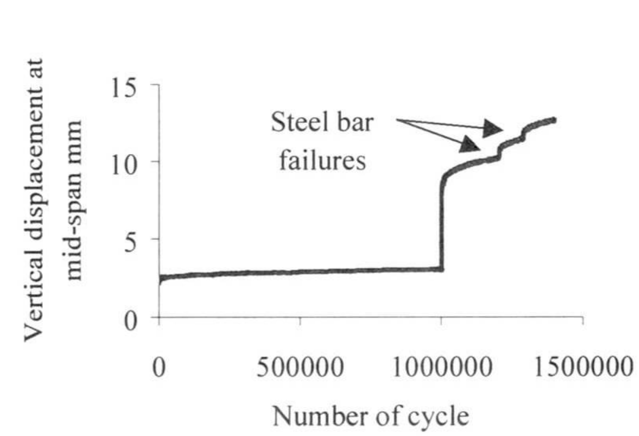

Fig 2-Maximal displacement of the slab 5 as a function of the number of cycles

Whole-Life Reliability Assessment of Deteriorating RC Structures

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Abstract

If a client has a large number of structures that are deteriorating at different rates and with different structural properties, then a method of prioritising the repair and strengthening works is required to ensure their overall structural integrity is maintained. The work described is one part of an extensive research programme, undertaken by Maunsell, to develop procedures for the risk-based management of a large number of deteriorating structures.

Maunsell have developed a methodology for predicting the residual strength of deteriorating reinforced concrete beams with time using both code-based (deterministic) and reliability based (probabilistic) methods of assessment . If an acceptable safe level of strength is defined, then the strength-time profile can be used to determine the latest time that repairs can be carried out on the structures without compromising safety.

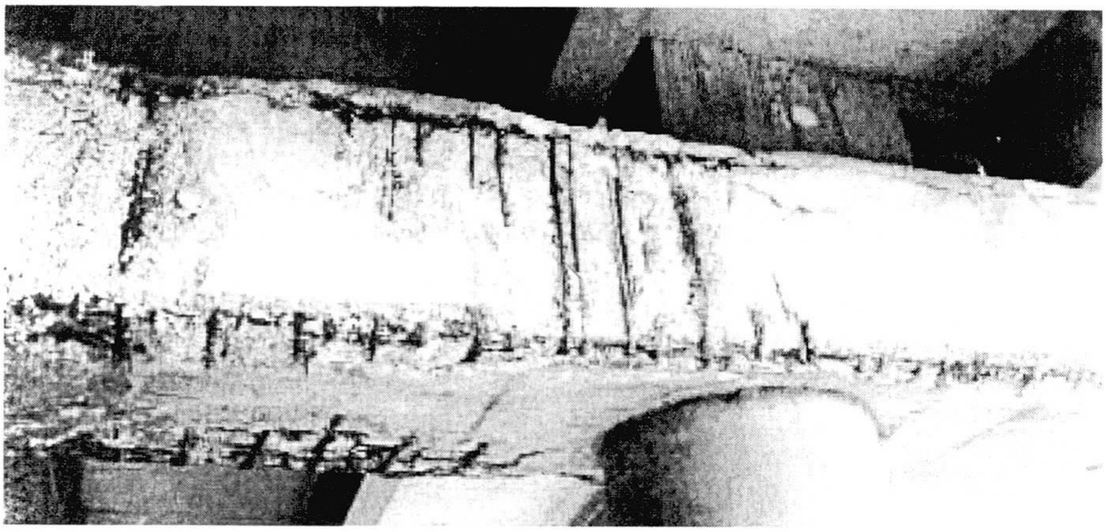

Fig. 1 An Example of a Deteriorated Crossbeam

The principal cause of deterioration of reinforced concrete highway structures in the United Kingdom is that of chloride induced corrosion of the reinforcement. An example of a deteriorated beam from the present work is shown in Fig. 1. In this specific case the source of chloride ions was from salt laden carriageway run-off leaking through defective deck joints onto the substructures.

A deterioration model has been developed to predict the time of arrival of chlorides at the beam surface, the time of corrosion initiation, the local rate of corrosion and whether the corrosion process has advanced sufficiently to cause delamination of the cover concrete. Corrosion is a stochastic process, therefore, the variability associated with each stage in the deterioration process and site measurement techniques were considered.

Due to the low sensitivity of the values used in the corrosion initiation process, combined with a lack of suitable data on corrosion thresholds, these values were treated as deterministic, although it was recognised that there may be significant variability in these values. The variability in the predicted corrosion rates and the half-cell monitoring technique were assessed. The variability found in the prediction of delamination was also assessed and found to be due primarily to the variability associated with the corrosion rate.

All the load components were considered as random variables. The probability distributions and statistical parameters were obtained from available literature. The deteriorated beam was assessed for: bending moment; shear force; and combined moment and shear. The calculation of moment resistance and shear capacity was based on existing code guidance. The section shear resistance was considered to be governed by the shear link contribution, the tension reinforcement via dowel action, and the aggregate interlock of the concrete. The reduction in capacity due to delamination of the tension reinforcement was taken into account by using the effective residual area of corroded steel bars. The resistance model for the combined moment and shear was based on reducing the bond strength between the steel and the concrete to incorporate concrete delamination. The model assumes that the bars may fail due to either insufficient bond strength or yielding as a result of reduced cross-sectional area.

A reinforced concrete beam, which supports a bridge deck that carries three lanes of traffic in each direction, was first analysed deterministically including predicted deterioration to identify the critical sections along the span. A critical section was defined as the section with the lowest capacity ratio (the ratio of strength to applied load). A capacity ratio of less than 1.0 implies that the margin of safety is less than that required by the code. The results of deterministic analysis indicated that the moment resistance was not at all critical for the beam considered.

The critical sections were then analysed probabilistically using First Order Reliability Method to determine the reliability profiles for shear and bond failure modes. An acceptable level of reliability was defined and the latest time at which repairs must be undertaken, such that structural integrity is not compromised, was determined.

The authors have demonstrated, using a sample beam, that reliability analysis is a powerful method of evaluating the long-term structural performance of deteriorating structures. These techniques have been used successfully in the development of a risk-based maintenance strategy to prioritise the repairs to the substructures on 21 kilometres of motorway viaducts in the UK.

Quality Control of Structural Projects

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Abstract

The collapse of a structure may bring about economic losses. Besides that, it represents a tragedy if a person suffers any physical or psychological injure, either permanent or not; and the tragedy would be even greater if there is lost a single human life. This tragedy will surely affect the professional body responsible of the referred structure (structural engineers, constructors, etc.), and every person or company that was involved with any phase of the construction process (architect, manufacturer, contractors, etc.). Nevertheless, this failure might have been easily avoided. Errors perpetrated in the phase of structural design constitute a big percentage of structural failure causes; but it is important to mention that they can be avoided by means of an adequate quality control of the structural design.

In the paper, the basic concepts related to quality control are presented, and they are mainly focused on the construction industry. After briefly stating that the success of the project is the satisfaction of the user's requirements and necessities, it is then continuously remarked along the whole paper. The quality control program is to be analysed as consisting of two mechanisms, the production control and the reception control. Both mechanisms are presented, explaining their responsible professionals, characteristics and objectives. Afterwards, both control mechanisms are compared, and after noting that the objective of them both is common, their differences are identified and explained, with a few examples.

A general overview of quality control is included, specifically related to the phase of structural design, where information related to the most important factors causing lack of quality is listed. A list of responsibilities of the structural project manager is also included, where another important issue regarding quality control is introduced: the importance of documents. The quality of structural designs, as well as the architectural one, is to be perfect, for the structure will be built based on them; any error or unclear information will lead to errors when working on site.

Three are the main areas where the quality control should be implemented are the following: revision of structural projects, control of modifications and structural design software. The purpose of the revision of structural projects is to thoroughly analyse all potential errors that could happen on site, and their effect on the resulting structure. Controlling all modifications introduced to the design, either at the office or on site, is vital; the designer must be informed of any change introduced to its design, in order to authorise them. Verifying all software to be used for analysis and design purposes is necessary in order to avoid incorrect results at the calculation stage.

The paper ends with a practical guide to control the quality of structural projects. It consists of three main areas: the production control, the reception control, and the modification control. At the production control analysis, eighth aspects are reviewed:

a) Computer software: highlighting that all software must be verify for validity and precision, and listing the necessary documentation regarding the software;
b) Structural systems: where it is stated the need to check the system chosen for the structure, for the high impact it has on the overall performance and cost;
c) Structural elements: focused to statistical control of the process, i.e., analysis of the reinforcement ration for different structural members, etc.;
d) Reinforcement details: explaining the importance of having plotted details of every situation where there might arise problems on site, such as detailing of connections among beams and columns;
e) Infrastructure foresight: since the introduction of ducts might affect structural behaviour;
f) Consumption of materials: because a high or low steel consumption per concrete volume might indicate the occurrence of an error at the structural design phase;
g) Specifications: stating their importance, as well as listing some aspects to be covered; and,
h) Plans and documents: indicating that the designer should keep a complete file of the initial design, as well as of the as-built structure.

The advantages of the reception control are stated, as well as an explanation of the difficulties of its implementation. The last item is related to modification control, where it is explained why they should be informed to the designer.

The paper is closes with some final comments of the author regarding the importance of the implementation of quality control programs by engineering firms.