Partially prestressed highway bridges

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Partially Prestressed Highway Bridges

Précontrainte partielle sur les ponts routiers

Teilweise vorgespannte Strassenbrücken

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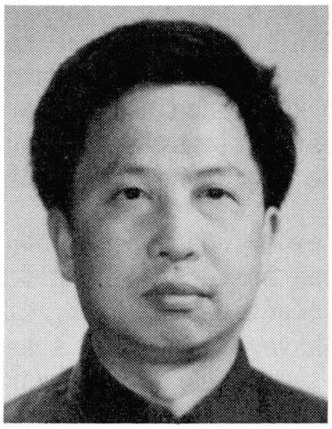

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SUMMARY

Systematic research on basic theories of the partially prestressed concrete bridges has been carried out. About 120 beams have been theories.This contribution presents the brief description of the experimental studies and emphasis put on some research results on flexural design. For partially prestressed concrete highway bridges, the design approach according to the prestressing degree and method to control cracking by means of the stresses of steel, are proposed.

RÉSUMÉ

Une recherche systématique sur les théories de base des ponts à précontrainte partielle a été réalisée en testant environ 120 poutres. Ce rapport présente une brève description des études expérimentales; l'importance est donnée aux résultats de recherche sur le dimensionnement à la flexion. Pour les ponts routiers à précontrainte partielle, ou propose und approche du dimensionnement basée sur le degré de précontrainte et sur le contrôle de le fissuration à travers le limitation des contraintes dans l'acier.

ZUSAMMENFASSUNG

Eine systematische Untersuchung der grundlegenden Theorien für teilweise vorgespannte Brücken wurde durchgeführt. Es wurden 120 Versuche an Balken durchgeführt. Dieser Beitrag enthält eine kurze Beschreibung der Versuche und hebt einige Forschungsergebnisse über Biegebemessung hervor. Für teilweise vorgespannte Brücken wird eine Bemessung entsprechend dem Vorspanngrad und die Rissbreitenbeschränkung über die Kontrolle der Stahl-Spannungen vorgeschlagen.

1. INTRODUCTION

The use of partial prestressing to highway bridges in China was begun in the middle seventies. At that times the design of PPC bridges was helped in the main by the existence of the European Specifications such as CEB, CP-110, FIP, as well as by informations gained from foreign previous experience and research publications. At present, while popularizing futher,the PPC at home is in the condition of that the experimental and practical engineering experience are accumulated. But up to now the PPC is getting not more generally used. Perhaps this is because of that quite a few of Chinese bridge engineers, who do not enough understand the PPC in substance, tend to be conservative and reluctant to take any risk with a new technology. Fundamentally speaking, it is accounted for the occurence that the knowledge about the strength, crack, stiffness etc. gained from tests and investigations are in sufficient, the design codes and analysis methodology on the whole are copies of the experience from abroad.

In oder to gather up more experinces on our own, to provide scientific and technical basis for revising the design code for highway bridges, to develop the design methodology fit to practice of China, since 1984, under direction of the author the CHRI and et.al have carried out a series of experimental studies and theoritical analysises on the fundamental theories of the PPC highway bridges. Based on the achieved results a more complete design recommendations and calculation system for PPC highway bridges has been proposed. In this contribution, some necessary introduction will be given in brief, but emphasis shall be merely put on the studies of crack because of the limit of the paper length.

2.BRIEF DESCRIPTION OF EXPERIMENTAL STUDIES

The whole work of the research is divided into three parts, i.e.the research on basis principles for flexural design, on basic design considerations for shear and on effects of the non-prestressing reinforcement.

The research on basic principles for flexural design of PPC beam can be summaried as follow:
(1) The ultimate flexural capacity
(2) The computing methods for normal stresses
(3) Design approach for crack control and calculation method of crack widths
(4) Calculation methods of deflection and stiffness
(5) The fatigue strength , cracking and deflection under cyclar loading
Above mentioned study tasks were brought to fruition through the rupture tests on 52 specimen beams, among them were 46 static loading and 6 cyclar loading. There were three types of tested beams. Their cross section forms involved conventional rectangular , T and I section. The forms respectively simulated the T-beams and the hollow plate beams of highway bridges. The I beams were 40cm high,prestressing by cold-strentched formed bars, but the others were 45cm high, prestressing by post-tensing high tensile strength wire tendons.The span of the specimens was 450cm long. The points of load application were symmetrically located at the one-third of span.

The studies on basic design considerations on shear includes following topics:
(1) The mechanisms of shear failure of PPC beams, the flexural capacity of inclined sections.
(2) The diagonal cracking and the computing methods for diagonal cracks.
(3) The diagonal cracking under repeated loading.
The basic data for the research on shear have been gained by the shear failure

tests on 44 beam specimens conducted in two batches. The first batch of test beams amounted to 24. Their steel percentages were just the same, but prestressing degrees, shear span ratios and stirrup percentages were distinctive. There were on 6 beams fatigue tests for inclinding sections have been accomplished.

The experimental studies on influences of non-prestresssing steel upon PPC beams were on two sides: creep of concrete and deflection. The studies have been carried out through the static tests on 20 specimen beams, among them eight have been observed over along term (above 900 days). In addition, the creep tests over 20 months on 23 concrete specimens have been made.The specimens and test beams were grouped by the grades of concrete and the ages at loading or the prestressing dergees and the steel percentages.

3. SOME RESEARCH RESULTS ON FAILURAL DESIGN

To designing the test beams the method according to prestressing degree was used.The method according to prestressing degree to design the PPC beams is a more simple, convenient, clear on idea and easy to use. Only basic checking calculations are need for designing. As the PD bring about a continuous transition from RC to PC, designing accordiing to PD is a practical and desirable unified design method for all RC, PPC and PC beams. The tests show that the tested PPC beams,designed like this (in acordance with PD), have higher ductility. The collapse of all the test beams have displaied plastic behaviour. The beam in brittle rupture have not emerged.

The measured limit flexural capacities of the tested beams of various beams having different PD, including RC beams whom PD is zero, have non-important to PD. In accordance with plasticity theory and the hypothesis of that the compressed region of concrete is a rectangle, the computing stresses are very close to the measured results. The average of the ratios of the measured stress to the computed is equal to 1.012, the standard deviation, σ=0.0645, the coefficient of the deviation, δ=0.652.

The measured deflections, strains and cracking on the varied tested beams have analogous characters. Therefore, whatever beams of RC, PPC or PC may be, a unified design approach and basic calculation methods can be used.

The strains measured on the beam specimens, prototype beams and tested bridges are better agreement with the plane section hypothesis.The average strains of concrete and steel along the depth of the tested beams is distributed as a straight line. Even to the failure moment the deformed sections all are still nearly plane.

Before cracking between the strains and loads a linear relation is kept better. After cracking, along with addition of the tested loads the increase of the strains of steel speed up,but after a short interval a relation near straight line is renewed. It is analogous to the pattern of variation in the intertia moments of the cracked sections. The stresses of concrete and steel, computing based upon elasticity theory, show very litter difference with the tested results.It can be proposed that the calculation approach like this way is dependable and exact enough.

As the modulus of rupture of concrete is not easy to define with addition of that the prestressing losses is often estimated not exactly,to estimate the cracking load of a beam accurately is not easy too. From our test results,it is can recommened that in practic the following formulae can be used to estimate the cracks moment of beams.

$Mf=(\sigma_c+R_l^b)W_o$ (1-1)

or $Mf=(\sigma_c+\gamma)W_o$ (1-2)

where σ_c = effective prestressing stress of concrete on tensile edge,
R_l^b = concrete tensile strength for designing,
W_o = resistance moment of the section to tensile edge,
γ = plastic coefficient.

Among the above two formulae the former is more conservative.

After decompressing the regular cracking patterns of PPC beams is similar to that of RC beams, thus the crack control for PPC beams can be considerated as for RC beams. The stable crack spacings of the specimens have assumed normal distribution. The aviations in the mean crack spacing are as a linear function of the d/μ or $d/\mu e$(where d--diameter of steel, μ--steel percentage, μe-steel percentage in effective region of the steel). By means of the linear regression, the mean crack spacing can be expressed as

$Lf=3.1+0.078d/\mu$ (cm) (2-1)

or $Lf=2.6c+0.18d/\mu e$ (cm) (2-2)

where c-cover of outer row bars

The checking calculations show: the ratios of the maximum crack width to the mean width are always 1.4 2, the average of the ratios for the tested beams is about 1.67.

the dominant factor exerting influence on crack width is steel stress. In the service range, the variation of the crack widths with the steel stresses is linear. From the test data, it has been found that the relationship between steel stress and maximum crack width can be taken as following form:

$W_{max}=a+b\sigma_s$ (mm) (3)

where σ_s -steel stress.

This expression is tenable on varied beams, having various section forms or different PD. Based on the test data of 46 beams and used the linear regression analysis, the achieved static results are a=0.0032, b=0.599**-3. While a unit of σ_s is 1MPa, the correlativity coefficient R=0.8, the standard deviation, σ= 0.0652. The tests show the effect of PD upon the value of the a and the b is not distinctive. It can be seen that along with the higher PD, in a certain limit, the a trend towerds a desrease in value, but b towards a incease. The statistic results for 24 tested beams are:

$a=a-0.07146(Md/Mu)**0.564$ (4-1)

and $b=0.6548+0.2873(Md/Mu)$ (4-2)

Because of the litter effect of PD on the a and b, it is reputed that the steel stresses already reflect the effect of PD. Therefore, when practic designing, to calculate the crack width the formulae (3) can be used, but the PD need not to be considerated once more. In accordance with the statistic analysis of the test data, the formula of the maximum width of crack (less than 0.3mm) is gained as following:

$W_{max}=0.1131+0.599**-3\sigma_s$(mm) (5)

The guarantee percentage of this formula is 95%. Using this formula, the cracks can be controled through control to steel stresses. Based upon recent crack theories and the test data a formula for calculating maximum crack width can be easy written down as follows:

$W_{max}=1.4\sigma_s Lf\psi/Es$ (6)

where ψ=non-uniformity factor of steel strains, to be computed from

$\psi=1.2(1-(Mf/M))$ (6-1)

Or $\psi=1.1-0.65R/(\mu e\sigma s)$ (6-2)

R-standard tensile strength of concrete,
Es-elastic modulus of steel.

Numerous checking computations show the agreement of the calculations by above mentioned formulae with test results are better.The compartions of our formulae with other formulae at home and abroad indicate that above mentioned formulae are not only reliable but also practical in designing PPC bridges.

The tests present the factitious tensile stresses of concrete bear obvious relation with the crack widths.Thus using factitious tensile stresses of concrete to control cracks is reasonable. But the tests also show:
(1) There do not exist the relationship in one by one between the factitious stresses and the crack widths.
(2) Corresponding with same factitious stresses, there may be exist large different beams.
(3) The relationships of the crack widths with the factitious stresses are different in different beams.
In recent years, using the allowable factitions tensile stresses, corresponding to the allowable crack widths,to control cracks is a usual approach in designing highway bridges. The allowable factitious stresses are stipulated in Codes, ex. JTJ 023-85(1) .The tests have discovered the allowable factitious stress in the Code JTJ 023-85 may be proper for the certain beams, but may be conservative in excess for some beams or may not on the safe side for another beams. It should be point out that a futher investigation and accumulation of experiment data must be continued. For the sake of to gain the reliable allowable factitious stresses possessed a sure guarantee percentage, the clear relatinships of factitious stresses with section forms, beam depths, prestressing type and PD must explored. The more proper calculation method for allowable factitious also must be sought.

472 measured data on 46 specimens showed both of the bilinear method and concept of effective moment of inertia (Ie) can reflect the variations in stiffness of the cracking PPC beam.

By the bilinear method the deflection of beam after cracking can be estimated from:

$$f=a\ {*}{*}2(Mf/(a_1EcI_0)+(M-Mf)/(a_2EcI_{0l})) \qquad (7)$$

where I_0 and I_{0l} are respectively the moment of inertia of non-cracking and cracking section. From the statistic results of the test data, the mean values of a1 and a2 are about 0.9, the standard deviation, $\sigma=0.15$, the linear correlativety coefficient R=0.95. Provided the guarantee percentage is adopted of 95%, then a1=a2=0.85, coinsided with of the Code JTJ 023-85.

A number of checking calculations indicate that, if the effective moment of inertia takes the following form:

$$Ie=I_0+(I_0-I_{0l})(Mf/M){*}{*}4$$

the computed deflections agree with measured on tested beams.

The fatigue tests on the cracking PPC specimens have showed, all failures due to fatigue occurred in the non-prestresssing steel, even through the prestressed steel wires are thiner. Therefore the fatigue of PPC beam can be consideed as RC beam.the fatigue tests also have showed there is not a beam occur fatigue failure after 2 million cycles of load. If the range of cyclic stresses is simulated the stresses under the deaded loads and the maximum service loads calaculated according to the Chinese Code JTJ 021-85(2). Therefore, at the moment in designing PPC highway bridges the effect due to fatigue usually need not be considered.

4.BRIEF INTRODUCTION OF THE TRAIL BRIDGES

In order to examine the reliability of the bridges designed by use of aforecitied research results, a few of trial bridges were designed and built.There are three trial bridges tested by us. The briefs of these bridges are summaried in the following table.

Table 1. The briefs of the trail bridges

Bridge Name		Red Flag Gully		ChenjiaZhang	NandaZang
Length of bridge(m)		2*20.5+30+5*20.5		2*16	15*13
Span length of beam(m)		20.5	30	16	13
Type of section form		T	T	T	hollow plate
Beam depth(m)		175	120	110	50
Prestressing degree		0.684	0.699	0.655	0.568
prestressing steel		5×24φ5 wires		4φ25 high tensile strength formed bars	
Non-prestesssing steel		20φ14		5φ16	20φ14
Computed crack width(mm)	by CEB-FIP Model Code(3)	0.0423	0.0320	0.0462	0.0480
	by ours	0.0434	0.0379	0.0399	0.0273
Factitious tensile stess(MP)		5.75 (5.03)	5.02 (5.91)	5.83 (4.00)	4.21 (6.38)
Tensile stress in non_ prestressing steel(MPa)		68.73	54.44	64.39	49.00

note:In brackets are the allowable factitious stresses defined by Code JTJ 023_85.

These trail bridge have already been opened to traffic in succession in recent years. While constructing the Red Flag Gully Bridge the static loading test on a beam spanning 20.5m have been carried out. After put into service on the Nandazhang Bridge and the Chengjiazhuang Bridge extensive load tests under heavier vechicle loads were performed. In addition two prototype beams,which are alike of the Nandazhang Bridge, were tested. The test results prove the actual state of the beams under traffic loads is better conformable to the designed.

The success of the trial bridges led to wider recognition of the both technical and economic benifits of application of partial prestrssing in bridges.

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