Advanced Materials Research Vols. 250-253 (2011) pp 2460-2467
Online available since 2011/May/17 at www.scientific.net
© (2011) Trans Tech Publications, Switzerland
doi:10.4028/www.scientific.net/AMR.250-253.2460

click for feedback
consult - comment - contact

Shear Stiffness of Segmental Joints in Cantilever Casting Concrete Bridges

Wei Zhang [1, a], Zonglin Wang [1, b] and Fadhil Naser Ali[1, c]

[1]School of Transportation Science and Engineering, Harbin Institute of Technology, Nangang District Haihe Road 202, Harbin, China, 150090

[a]zw2007131@163.com, [b]wangzonglin@163.vip.com, [c]ali_hu73@yahoo.com

Keywords: Shear Stiffness, Segmental Joints, Cantilever Casting.

Abstract. Joints between segments in cantilever casting concrete bridges require special attention in design and construction. These joints introduce discontinuity in the bridge; furthermore weaken the connection stiffness and strength of corresponding section, which may lead to excessive downwarping of bridge. Experiments were conducted to assess the shear stiffness of segmental joints section. The parameters studied included monolithic non-joints, joints roughened, joints roughened with shear-key. It was found that the shear stiffness of jointed section is largely lower than that of non-jointed section; however, the shear-key can effectively enhance the shear strength and especially shear stiffness of the joints section. Measures are proposed for shear-key design, and may provide a rational basis for the design of cantilever casting concrete bridges.

Introduction

In recent decades, long-span prestressed concrete continuous bridge and continuous rigid frame bridge have become increasingly popular in china, however, some bridges appeared excessive downwarping (more than 100mm) after several years of operation, which results in not only large increasing of maintenance cost and unaesthetic, but also reduction of the degree of structure security. Concerning the factors lead to excessive long-term deflection of bridge, most scholars presently focus on the shrinkage and creep of concrete, whereas ignoring the effect of shear stiffness reduction at segmental joints section on long-term deflection of bridges.

Long-span prestressed continuous bridges and rigid frame bridges usually are constructed by balanced cantilever casting in china, thus there are necessarily relatively weak joints among segments whose construction technology and quality will significantly impact on structure. Actually, there are considerable joints with poor quality in construction whose stiffness is greatly weaker than monolithic structure. However, it is consistently assumed that structure is ideally continuous without joints in bridge design and structural analysis, which results in the deviation between theory and practice. Under long-term loads, the weaker joints will yield large shear creep. The cumulative deflection of all joints consequently leads to the increasing of deflection necessarily, which should not be neglected in design. According to structural mechanics, the theory deflection is:

$$f=\sum\int\frac{\bar{M}M_{\mathrm{p}}ds}{EI}+\frac{\bar{N}N_{p}ds}{EI}+\frac{k\bar{Q}Q_{p}ds}{GA}\,. \tag{1}$$

Nevertheless, deflection led by axial force and shear is usually not considered, which is feasible for normal concrete structure, rather than cantilever casting segmental concrete bridge. Thus, deflection caused by shear stiffness reduction of segmental joist should be considered into the design of bridges. Though some scholars have studied shear strength of precast segmental joints [1,2,3] or tensile strength of cast-in-place joints [4,5], there is relatively little information available on the shear stiffness and design of joints between segments in cantilever casting bridges, some are confined to

consult
comment
contact
click for feedback

All rights reserved. No part of contents of this paper may be reproduced or transmitted in any form or by any means without the written permission of TTP, www.ttp.net. (ID: 218.8.97.214-17/05/11,15:49:29)

theory analysis [6]. In this paper, systematic experimental work was conducted to study the shear stiffness of segmental joints, and measures are proposed for shear-key design and shear stiffness improvement of joints section according to the results of experiment.

Experimental Setup

The experiments includes 3 specimens which is respectively monolithic non-joints, joints roughened and joints roughened with shear-key according to the different shear stiffness at the corresponding joints section. In the 3 specimens, the monolithic non-joints specimen was shaped at once casting, and the other 2 specimens with joints were segment casting. The concrete grade applied in the 3 specimens is C60, and the constructional steel bar applied is HRB335 Φ8. Fig.1 shows the detail of specimen and the layout of measuring points [7]. Fig.2 shows the practical load device.

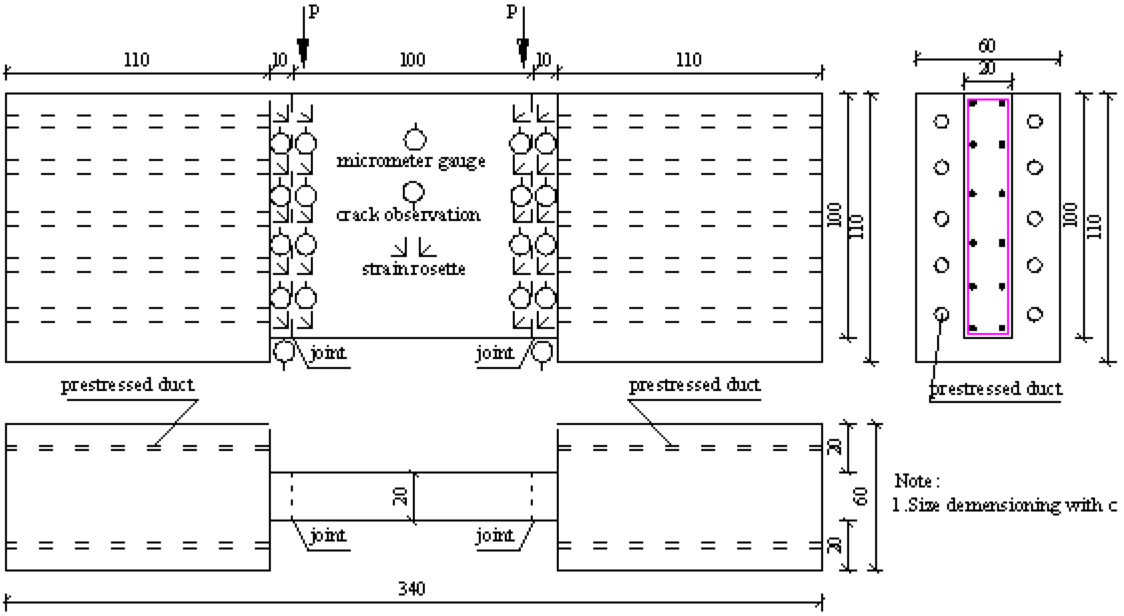


Fig.1 Specimen constructional detail and layout of measuring points (unit: cm)

Fig.2 Loading device

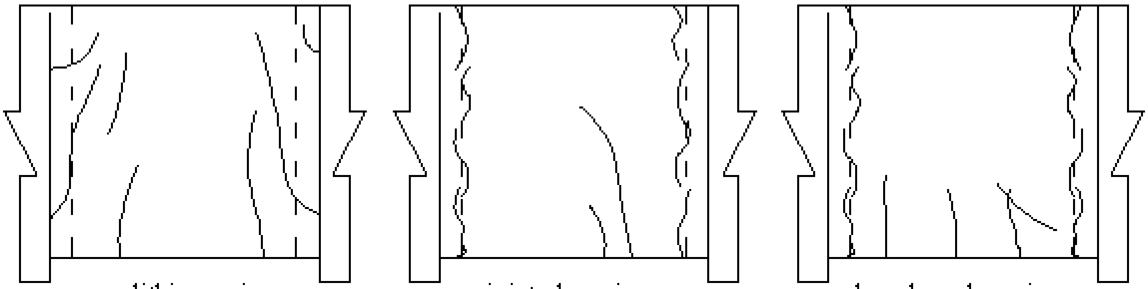
Fig.3 The strain gage layout of shear-key

As is shown in Fig.1 and Fig.2, loads were applied symmetrically on the inner side of the joint through 2 2500kN jacks, meanwhile set strain rosettes and micrometers along vertical at the both side of each joint to test the shear stress distribution and the deformation of joints section, thus educing the shear stiffness of joints. As for the specimen with shear-key, 10 Φ16 rebars were applied as shear-keys passing the joints section, which were embedded strain gages to monitor shear-keys stress during loading as is shown in Fig.3, the strain gages were built-in the shear-keys at the points of joints.

click for feedback
consult - comment - contact
consult comment contact
click for feedback

Experimental Results and Discussion

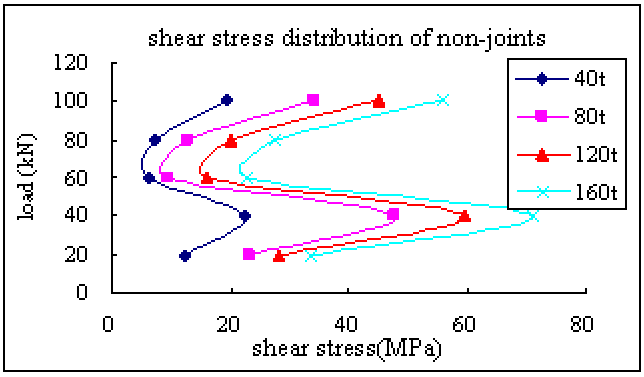
The crack shape. The crack shape of monolithic specimen is typical cleavage failure of deep beam; there is no crack along the corresponding joints section which means the margin of shear stiffness of non-joints section and. The crack shape of jointed specimen and shear-keyed specimen is analogous, the first crack formation of the both developed on the trisection of span and propagated obliquely; and both cracked and spread along the vertical joints with loading until throughout the joints section; however, the crack along the vertical joints of jointed specimen appeared earlier at 800kN compared with 1000kN of the shear-keyed specimen; moreover, the crack width of jointed specimen is wider than that of shear-keyed specimen, that is the shear stiffness of jointed specimen is lower than that of shear-keyed specimen. The final crack shape of each specimen is shown in Fig.4.



monolithic specimen jointed specimen shear-keyed specimen

Fig.4 The final crack shape of each specimen

The shear stress distribution. It was found through the shear test that the shear stress distribution differs with that of pure shear, which mainly led by the local pressure as is shown in the Fig.5~Fig.7.



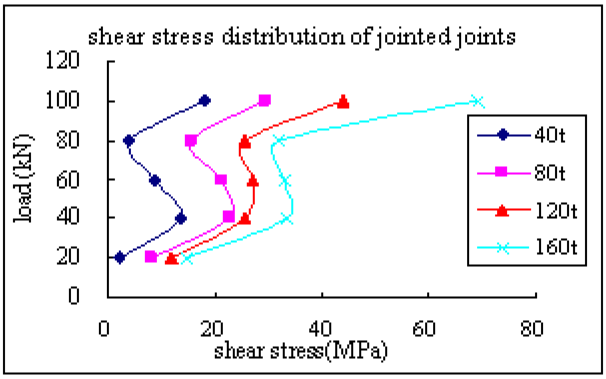


Fig.5 shear stress distribution of non-joints (MPa) Fig.6 shear stress distribution of joints (MPa)

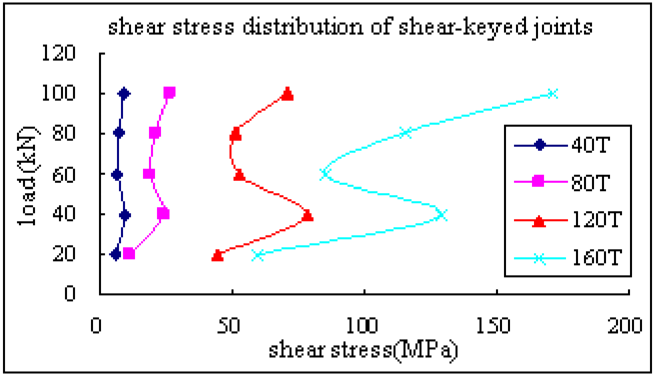


Fig.7 shear stress distribution of shear-keyed joints (MPa)

Moreover, the mean values of shear stress increase with the increasing of shear stiffness of the joints section. As is shown in Table 1~Table 3, it is non-jointed section, shear-keyed section and jointed section in sequence according to descending order of the mean values of shear stress.

click for feedback
consult - comment - contact

Table 1 Shear stress distribution of non-joints section (unit: MPa)

Test point	Load grade			
	400 (kN)	800 (kN)	1200 (kN)	1600 (kN)
100	19.37	34.16	45.03	55.89
80	7.24	12.79	20.21	27.63
60	6.45	9.27	16.12	22.97
40	22.48	47.78	59.42	71.06
20	12.59	23.07	28.37	33.68
Mean	13.63	25.41	33.83	42.24

Table 2 Shear stress distribution of shear-keyed section (unit: MPa)

Test point	Load grade			
	400 (kN)	800 (kN)	1200 (kN)	1600 (kN)
100	8.83	26.13	71.00	170.96
80	7.26	21.10	51.13	115.37
60	6.56	19.11	52.55	85.12
40	10.16	24.09	78.20	128.96
20	5.73	11.21	44.60	59.57
Mean	7.71	20.33	59.50	111.99

Table 3 Shear stress distribution of joints section (unit: MPa)

Test point	Load grade			
	400 (kN)	800 (kN)	1200 (kN)	1600 (kN)
100	18.29	29.23	43.93	69.27
80	4.26	15.48	25.76	32.05
60	8.76	21.30	27.29	33.27
40	13.78	22.54	25.79	33.51
20	2.25	8.25	11.97	15.05
Mean	9.47	19.36	26.95	36.63

The stress of shear-keys listed in the Table 4 shows that shear-keys shared shear force efficiently, and some yielded even to the normal strength value of HRB335 rebar; it also can be seen in Table 5 that the sharing ratio descends with the increasing of load, which means some shear-keys began to yield.

Table 4 Stress of shear-key (MPa)

Shear-key Number	Load grade			
	400 (kN)	800 (kN)	1200 (kN)	1600 (kN)
1	-67.6	-97.2	-206.8	-187
2	-40.4	-52.2	-49.8	-42.8
3	-15	-13.8	14.4	29.2
4	13.4	33.6	123.8	191.2
5	61.2	125.8	300.6	350.4
6	-149.8	-192.8	-302.4	-282.6
7	-125	-148	-161.2	-175.6
8	-115.6	-123.6	-84.6	-57.4
9	-85.6	-75.4	-21.2	25.6
10	-71.2	-33.2	101.6	207.4

click for feedback
consult - comment - contact
consult comment contact click for feedback

Table 5 Force and sharing ratio of shear-keys

Load（kN)	400	800	1200	1600
shear-keys force(kN)	149.8	180.1	274.8	311.5
Shear-key force/Load	0.37	0.23	0.23	0.19

Shear deformation results. The average joints shear deformation results of each specimen are listed in Table 6, it is found that the relative deformation of monolithic non-jointed specimen at the corresponding joints section is 0.072mm when the both jack loading to 1600kN, which is smaller greatly than that of jointed specimen (0.361mm) and that of shear-keyed specimen (0.253mm). As is shown in Fig.8, the deformation curve of monolithic non-jointed specimen is smooth and close to straight line whose slope is higher than the other 2 curve, which shows that the shear stiffness of the corresponding joints section is relatively higher and the section still woks at elastic stage. On the other hand, obvious inflexion led by crack of joints has appeared in the curve of jointed specimen since 800kN, and the maximum of the relative deformation is 0.319mm which is 5 times than that of non-jointed specimen and 1.42 times than that of shear-keyed specimen; that is, the shear stiffness of joints is only 20%(1/5) of the shear stiffness of the monolithic non-jointed section’s. Moreover, the curve of shear-keyed specimen is smoother and the inflexion is inapparent, which indicates the shear-keys shared with shear force and contribute to the shear stiffness of jointed section compared with that of jointed specimen, so as to make the structure works better as a whole.

Table 6 Average relative deformation of joints section (unit: mm)

Specimens	400 (kN)	800 (kN)	1000 (kN)	1200 (kN)	1400 (kN)	1600 (kN)
Non-joints	0.012	0.029	0.038	0.049	0.060	0.072
Joints with shear-key	0.047	0.100	0.143	0.193	0.223	0.253
Joints	0.052	0.081	0.114	0.227	0.252	0.361

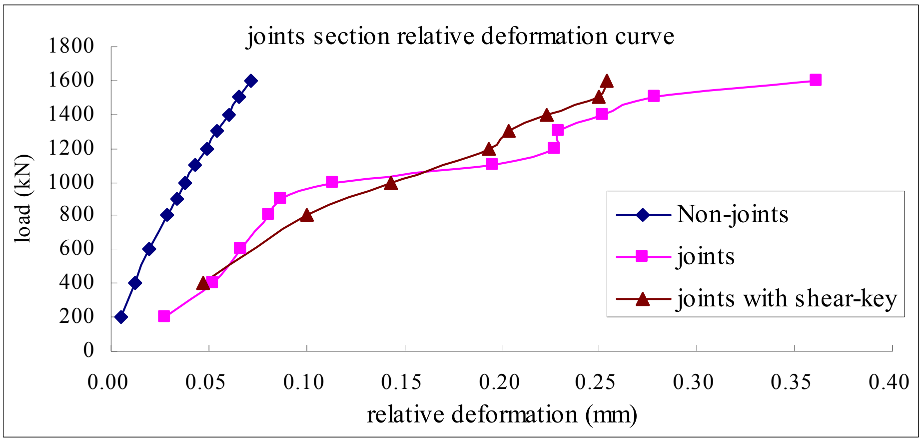


Fig.8 Joints section relative deformation curve

The shear stiffness of a section is kGA, where, k and A are related to the shape and the size of the section; once the layout of the section are determined, the shear stiffness is only related to the shear modulus G, that is, the decreasing of shear stiffness is equivalent to the decreasing of G. Thus, the shear stiffness of joints is only 20%(1/5) of the shear stiffness of the monolithic non-jointed section, which indicates that the shear modulus G of joints concrete is lower 5 times than that of non-joints concrete.

In order to examine the test result, finite element model was built by ANSYS 10.0 as is shown in Fig.9. Solid65 was applied to the concrete element and link8 was applied to rebars and shear-keys element. The concrete joints were simulated by a thin volume whose shear modulus G was 5 times lower than the G of non-joints, and the shear-keys were simulated separately by BISO model. The concrete constitutive relations fitted by MISO model, whose ascending branch was applied according

click for feedback
consult - comment - contact
consult comment contact
click for feedback

click for feedback
consult - comment - contact

to GB50010-2002 code of china and whose descending branch was applied following Hongnestad model [8].

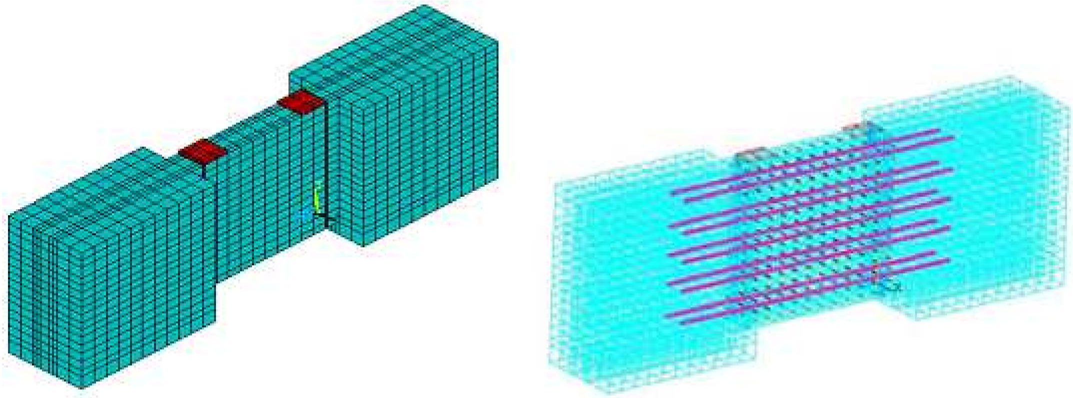


Fig.9 Finite element model

The average relative deformation of joints calculated by the finite model is shown in Table 7, it can be found that the calculated results is close to the test results shown in Table 6, which verifies the validity of experiment further. The curves in Fig.10 are identical with the curves in Fig.8 except for the earlier inflexion (600kN) of joints in Fig.10 compared with that in Fig.8, which maybe led by higher strength of the specimen concrete.

Table 7 Calculating average relative deformation of joints section (unit: mm)

Specimens	Load grade					
	400 (kN)	800 (kN)	1000 (kN)	1200 (kN)	1400 (kN)	1600 (kN)
non-joints	0.012	0.028	0.036	0.046	0.058	0.071
shear-keyed joints	0.047	0.093	0.122	0.159	0.206	0.263
joints	0.046	0.125	0.209	0.219	0.264	0.319

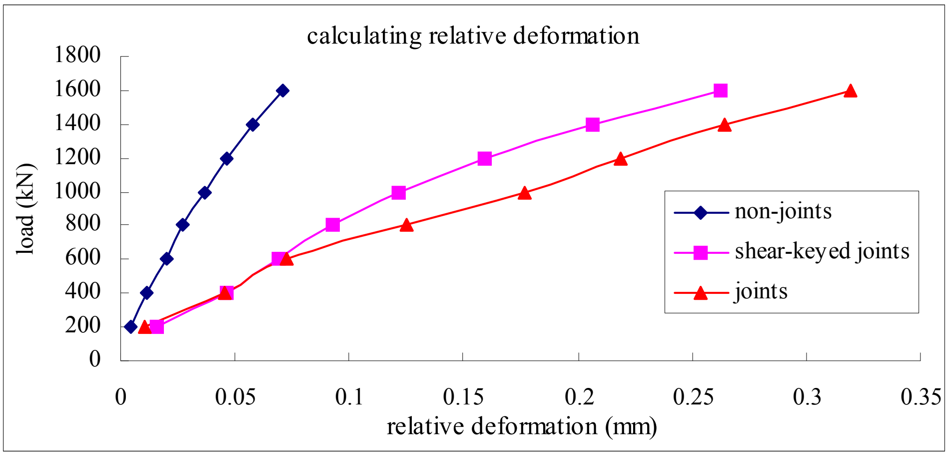


Fig.10 calculating relative deformation curve (mm)

Based on the above analysis, the area of shear-keys can be educed as following: the shear stiffness of monolithic non-jointed section and shear-keyed joints may be expressed respectively by (2) and (3)

$$k_cG_cA_c + k_sG_sA_s. \quad (2)$$

$$k_cG_c'A_c' + k_sG_sA_s + k_kG_kA_k. \quad (3)$$

Where, A_c=A-A_s, A_c'= A-A_s-A_k; A, A_c, A_c', A_s and A_k is respectively the area of joints gross section, concrete without shear-key, shear-keyed concrete, rebars passing joints, and shear-keys; k_c,k_s, k_k is respectively the shape factor of concrete, rebar and shear-key, 6/5 for rectangle, 2 for thin-walled pipe,

consult
comment
contact
click for feedback

click for feedback
consult - comment - contact

and 12/5 for thin-walled box and I-section; G_c and G_c' is respectively the shear modulus of monolithic non-jointed section and jointed section, where $G_c'=0.2G_c$ educed from the shear test. Let (2) = (3), obtain that

$$A_k = \frac{k_c(G_c - G_c')(A - A_s)}{k_k G_k - k_c G_c'} = \frac{0.8k_c G_c (A - A_s)}{k_k G_k - 0.2k_c G_c}. \qquad (4)$$

The formula (4) indicates that it needs area of A_k to ensure the stiffness of jointed section is equal to that of monolithic non-jointed section. Generally, the area of rebars passing joints is far less than the area of joints gross section, that is $A_s \ll A$, thus the formula (4) can be approximately expressed as below

$$A_k \approx \frac{0.8k_c G_c A}{k_k G_k - 0.2k_c G_c}. \qquad (5)$$

Therefore, the jointed specimen in this test needs the shear-keys of $A_k=27586.2\text{mm}^2$ to reach the shear stiffness of the monolithic non-jointed section. However, it is necessary for the formula (4) or (5) to point out that the effect of prestress contributing to the shear stiffness of joints is not taken into account.

Conclusions

Experiments were conducted to assess the shear stiffness of segmental joints in cantilever casting concrete bridge. The shear stiffness of joints was investigated aimed at different connection stiffness of the corresponding joint section. The following conclusions are drawn from these experimental results:

1. The crack shape of monolithic specimen is typical cleavage failure of deep beam, and there is no crack along the corresponding joints section which means the margin of shear stiffness of non-joints section and. The crack shape of jointed specimen and shear-keyed specimen is analogous; however, either the later appearance of inflexion of relative deformation curve or the smaller width of crack shows the higher shear stiffness of shear-keyed joints section in contrast to that of joints.
2. The mean values of shear stress increases with the increasing of shear stiffness of the joints section. It is non-jointed section, shear-keyed section and jointed section in sequence according to descending order of the mean values of shear stress.
3. shear-keys can share shear force efficiently with concrete joint, the sharing ratio descends from 0.37 down to 0.19 when load increasing from 400kN to 160kN, which means some shear-keys began to yield and the area of shear-keys is insufficient.
4. The shear deformation results shows that the shear stiffness of joint is lower 5 times than that of non-jointed section, that is equivalent with the shear modulus G of joint lowering 5 times than that of non-jointed section, which have been verified by finite elements analysis.
5. Based on the experimental data and finite element analysis, the formula calculating the total area of shear-keys is proposed, however it is necessary for the formula (4) or (5) to point out that the effect of prestress contributing to the shear stiffness of joints is not taken into account.

Acknowledgement

This experiment is financially supported by the Heilongjiang province highway key engineering research project—Control of Crack and Deformation of Cold-region Long-span Prestressed Concrete Continuous Bridge (2008KJZB03).

consult
comment
contact
click for feedback

References

[1] Xiangming Zhou, Neil Mickleborough, and Zongjin Li: ACI Structural Journal. Jan. (2005), p. 3.

[2] Oral Buyukozturk, Mourad M. Bakhoum, and S. Michael Beattie: Journal of Structural Engineering. Vol. 116 (1990), pp. 3380-3401.

[3] Fengjun Liu, Hehua Zhu, Ning Yu: Advanced Material Reasearch. Vols. 163-167 (2011), pp, 1286-1290.

[4] Mingquan Zhong, Kaijing Zhang: Journal of Southwest Jiaotong University. Vol. 29 (1994), p, 429. In Chinese.

[5] Kaijing Zhang, Renda Zhao, Zhongguo Ma: Journal of Southwest Jiaotong University. Vol. 29 (1994), p, 436. In Chinese.

[6] Rongxia Wang, Hongjiang Li, Kexi Jin: Advanced Material Reasearch. Vols. 163-167 (2011), pp, 1364-1368.

[7] Shangyan Wang: Journal of Railway Construction. Vol. 3 (1997), p, 23. In Chinese.

[8] Xinmin Wang: Ansys Engineering Structure Numerical Analysis. Oct.(2007). In Chinese.

click for feedback
consult - comment - contact

consult
comment
contact
click for feedback

Advanced Building Materials
doi:10.4028/www.scientific.net/AMR.250-253

Shear Stiffness of Segmental Joints in Cantilever Casting Concrete Bridges
doi:10.4028/www.scientific.net/AMR.250-253.2460

click for feedback
consult – comment – contact

consult
comment
contact
click for
feedback