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Advances in Bridge Engineering (2023) 4:19
https://doi.org/10.1186/s43251-023-00099-w

Advances in
Bridge Engineering

ORIGINAL INNOVATION **Open Access**

A yield curvature model considering axial compression ratio

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Abstract

This study proposed a yield curvature prediction model considering axial compression ratio with exponential function which is improved on the basis of the specification effective yield curvature prediction model. Parametric moment–curvature curves approach was used to verify that the yield curvature is greatly affected by the section size, the yield strength of longitudinal steel bar and the axial compression ratio. On the basis, the yield curvature under different levels was obtained by Xtract and parametric moment–curvature curves approach, the result shows that with the increase of axial compression ratio, the yield curvature also increases, which is roughly a linear relationship. Subsequently, combined with the specification and considering the influence of axial compression ratio, a new yield curvature prediction model is proposed based on a massive sample space obtained by parametric moment–curvature curves approach. Moreover, by comparing with the experimental database of PEER, the accuracy of new prediction model is verified, and the result shows that the new prediction model is suitable for estimating yield curvature of square section columns.

Keywords: Yield curvature, Axial compression ratio, Prediction model

1 Introduction

Bridge columns are structural elements that support the weight of the bridge. These columns are subject to various types of loads, including horizontal and vertical loads, and moments caused by bridge displacement. The design of the column is crucial to the safety and reliability of the structure, and the failure of the column will lead to catastrophic consequences (Cornell et al. 2002). Axial compression ratio is an important design parameter that significantly affects the seismic performance of columns. This is demonstrated in prediction models proposed by researchers. Ho (Ho and Pam 2010) proposed a prediction model of curvature in collapse damage state, in which the axial compression ratio is an important parameter. Moreover, in the specification, the axial compression ratio plays a crucial role in collapse damage state (Ministry 2020). However, for the effective yield curvature, the influence of axial compression ratio has not been considered by some researchers and specifications (Ministry 2020; Olivia and Mandal 2005; En 2005; ATC-40. 1996). The effective yield curvature is obtained from the actual moment–curvature curve equivalent to the ideal elastic–plastic moment–curvature curve, and the ideal elastic–plastic moment–curvature curve must pass through the point corresponding to the yield curvature, but it is different from the definition of yield curvature, moreover, some scholars have considered the influence of axial compression ratio in the yield curvature prediction model (Hernández-Montes and Aschleim 2003; Zhong et al. 2022a). In the prediction model proposed by Hernández (2003), the yield curvature increases with the increase of axial compression ratio. The yield curvature prediction model proposed by Zhong (Zhong et al. 2022a) also considers the influence of axial compression ratio, the yield and effective yield curvature prediction model proposed by scholars and specifications is shown in Table 1. Although the yield curvature prediction models proposed by Hernández (2003) and Zhong (2022a) have been verified, there are still the following problems: (1) it is inconvenient to remember; (2) prediction model is not applicable when the axial compression ratio is 0.

Finite element analysis has become a popular choice among researchers for studying bridge columns due to its advantages in terms of resource efficiency and convenience, as compared to experimental methods. With the aid of finite element analysis software, scholars extensively investigate and optimize the design of bridge columns. Su (2019) obtained the yield curvature of bridge columns using Xtract and implemented it into a formula to calculate the displacement of steel reinforcement slip. Zhang (2020) studied the factors affecting the top displacement of high-strength column through ABAQUS. Aldabagh (2022) deduced the prediction model of drift ratio of different damage states by establishing samples with OpenSees. Therefore, Xtract was employed as a tool to validate the yield curvature in this study.

In this study, the yield curvature is first defined, and the section information of the columns is replaced by the expression by using the parametric moment–curvature (M-ϕ) curves approach (PMCA), and the M-ϕ curves can be obtained based on the plane hypothesis model and the stress–strain models of longitudinal reinforcement and concrete. On this basis, PMCA was employed to discuss the influence of section size (L), axial compression ratio (R_{ac}), longitudinal reinforcement ratio (ρ_l), stirrup reinforcement ratio (ρ_s), concrete compressive strength (f_{co}) and yield strength of longitudinal steel bar (f_y) on yield curvature, and then remove the parameters that have little effect on yield curvature. On this basis, some levels under different L, f_y and R_{ac} were set, and the yield curvature was obtained by Xtract and PMCA and compared. Moreover, some columns whose failure form is flexural failure are selected and the experimental yield curvature is obtained. The yield curvature prediction model considering the influence of R_{ac} was

Table 1 Summary of some prediction models

Index	Source	Prediction model
Effective yield curvature	Chinese (2020)	$\varphi_y^* = 1.957\varepsilon_y/L$
	Olivia (Olivia and Mandal 2005)	$\varphi_y^* == \frac{f_y}{E_s(1-k)L}$
	European (En 2005)	$\varphi_y^* = 2.1\varepsilon_y/L$
	California (ATC-40. 1996)	$\varphi_y^* = 2.2\varepsilon_y/L$
Yield curvature	Hernández (Hernández-Montes and Aschleim 2003)	$\varphi_y = \frac{\varepsilon_y}{L}\left[2.3 - (0.6 - 2.5R_{ac})^2\right]$
	Zhong (Zhong et al. 2022a)	$\varphi_y{=}0.0054_{\rho_s^{-0.0065}\rho_l^{0.0341}R_{ac}^{0.2097}L^{-1.0160}}$

φ_y^* = effective yield curvature; φ_y = yield curvature; $\varepsilon_y = f_y/E_s$; f_y = the yield strength of longitudinal steel bar; E_s = the elastic modulus; L = section size; R_{ac} = axial compression ratio; ρ_s = stirrup reinforcement ratio; ρ_l = longitudinal reinforcement ratio proposed based on a massive sample space obtained by PMCA and compared it with experiments.

2 Definition of yield curvature

The order of failure of the bridge column is as follows: the cracks first occur, then the first yielding of longitudinal steel bars is observed, followed by the spalling of the cover concrete, the crushing of the core concrete, and the fracture of the stirrup in the final stage. The section curvature corresponding to the first yielding of longitudinal steel bars is taken as the yield curvature (ϕ_y) of column in this study, as shown in Fig. 1. Strain can be used as an index to judge the damage state (Calvi and Kingsley 1995; Priestley et al. 1996). When the strain of the longitudinal steel bars reaches, it can be considered that the longitudinal steel bars has yielded for the first time, and the corresponding curvature is ϕ_y.

3 Parametric *M-φ* curves approach

Zhong (2022a) proposed a parametric moment–curvature (M-ϕ) curves approach (PMCA), which transformed discrete longitudinal steel bars into 'steel loop', the thickness of the 'steel loop' can be approximately represented to $d_0 = (\rho_l LW) / (2L + 2W\text{-}4C_0)$, where L and W are the size of the bridge column section, C_0 is cover concrete thickness, and so that three important parts (cover concrete, core concrete and longitudinal steel bars) are continuous sections. Each part can be represented by thickness information: T_{uc}, T_{cc}, and T_s, as shown in Fig. 2. Then, based on the plane hypothesis model and the stress–strain model of concrete (proposed by Mander et al. (1988)) and steel (steel01), the balance between the axial force and the reaction force of the column is established and moment is obtained. The stress–strain model is shown in Fig. 3, where ε_{co}, ε_{cc} and ε_{cu} are peak strain of cover concrete, peak strain of core concrete and ultimate strain of core

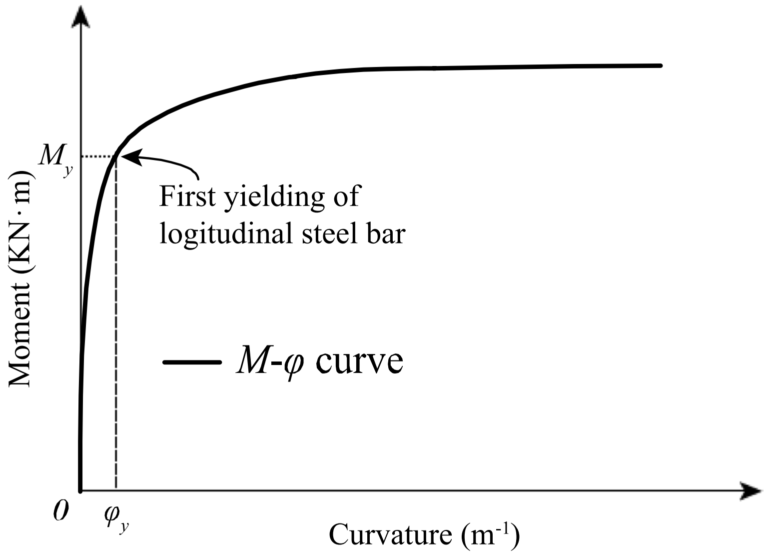


Fig. 1 Definition of yield curvature

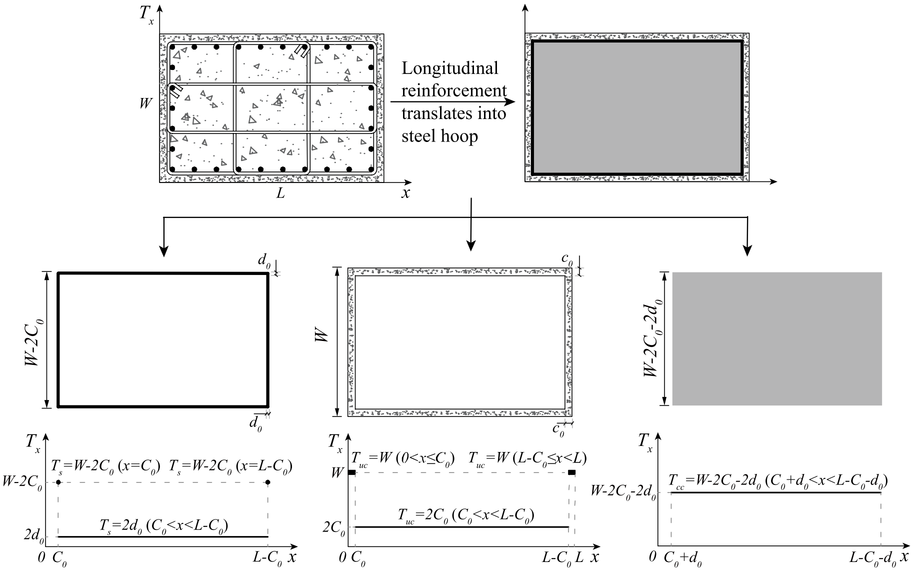
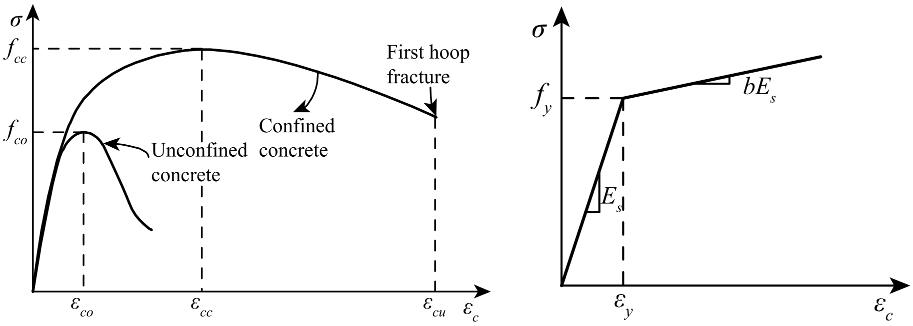


Fig. 2 Parametric *M*-*φ* curves approach



(a) (b)

Fig. 3 **a** Concrete04; and **b** Steel01 model

concrete, f_{co} and f_{cc} are the compressive strength of cover and core concrete, b is strain-hardening ratio.

The ϕ_y prediction model proposed by Zhong (2020) does not consider the influence of f_y, and the ϕ_y cannot be calculated when the R_{ac} is 0. Therefore, this study attempts to establish a ϕ_y prediction model of six parameters, and then remove the parameters that have little influence on the yield curvature. 9^6(531,441) levels are established to fit the prediction model through PMCA, and the parameters information is shown in the Table 2.

The exponential function is used for fitting to directly obtain the influence of each parameter on ϕ_y. The form of the expression is as follows:

$$\varphi_y = aL^{a_1}(1 - R_{ac})^{a_2}\rho_l^{a_3}\rho_s^{a_4}f_{co}^{a_5}f_y^{a_6} \tag{1}$$

where a, a_1, a_2, a_3, a_4, a_5, a_6 are coefficients of exponential function. The greater the absolute value of a_1 to a_6, the greater the influence of parameters on ϕ_y. The fitted expression is shown in Eq. 2.

Table 2 Sample space parameter information

Parameter	Symbol	Lower	Increment	Upper	Unit
Section size	L	1.0	0.25	3.0	m
Axial compression ratio	R_{ac}	0.06	0.03	0.3	
Longitudinal reinforcement ratio	ρ_l	0.01	0.0025	0.03	
Stirrup reinforcement ratio	ρ_s	0.01	0.0025	0.03	
Concrete compressive strength	f_{co}	30	2.5	50	MPa
Yield strength of longitudinal steel bar	f_y	300	25	500	MPa

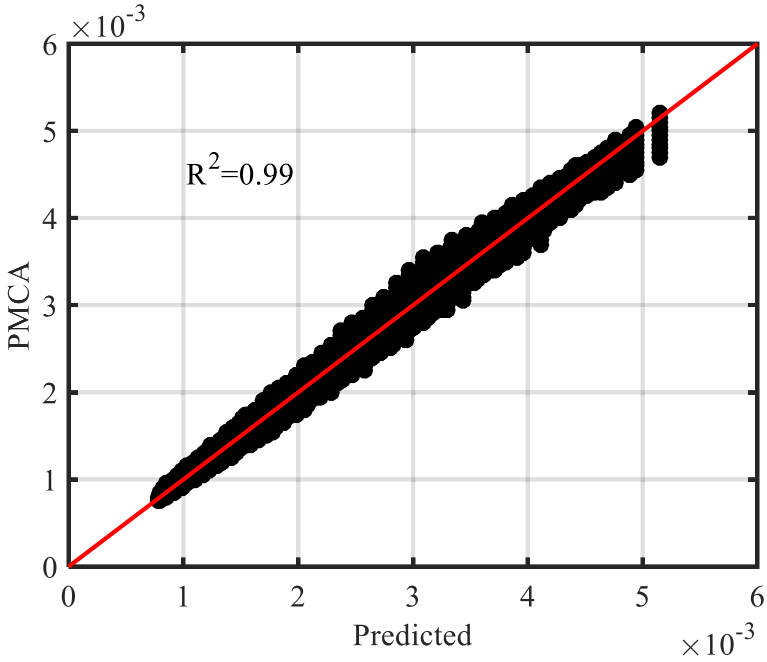


Fig. 4 Comparison of fitted expression with PMCA

$$\varphi_y = 7 \times 10^{-6} L^{-1.03} (1 - R_{ac})^{-0.96} \rho_l^{0.038} \rho_s^{-0.0015} f_{co}^{0.104} f_y^{0.98} \quad (2)$$

By comparing the fitted expression and PMCA in Fig. 4, the effect is not bad. From the fitted expression, ϕ_y is significantly influenced by L and f_y, and as f_y increases or L decreases, the ϕ_y increase accordingly, as reported in previous studies. Priestley (1998) reported that L and f_y have a great influence on the curvature of the slight limit state, which is inversely proportional to L and proportional to f_y. The coefficient of (1-R_{ac}) is also high, therefore, based on the effective yield curvature prediction model combined with the specification, this study proposes a yield curvature prediction model considering R_{ac}. Hernández (2003) studied that as R_{ac} increases, the curvature of the slight limit state also increases, which is consistent with Eq. 2.

4 Comparison between numerical simulation and PMCA

4.1 Finite element model

Xtract was used in this study to verify the accuracy of PMCA and provide a control group for subsequent studies. According to the main influence parameters obtained by PMCA, some levels of different L, f_y and R_{ac} are set, as shown in Table 3.

Xtract is an effective software for obtaining ϕ_y, which can calculate the moment–curvature curve of column section and output ϕ_y directly. Therefore, a square section column was established by Xtract, and the parameters of cover concrete, core concrete and longitudinal steel bars are defined. The cover and core concrete material model proposed by Mander et al. (Mander et al. 1988) are adopted in Xtract. In this study, the concrete grade is C50, the cover concrete strength is 32.4 MPa. The core concrete strength is 42.1 MPa in Test 1 and 42.8 MPa in Test 3. The yield strain of core concrete is 0.0035 in Test 1 and 0.00365 in Test 3. The elastic modulus of cover and core concrete is 3.45×10^4 MPa. The longitudinal reinforcement ratio is 1.13%, the yield strength of stirrup is 360 MPa, the stirrup ratio is 1%, and the thickness of cover concrete is 0.04 m, the other parameters are shown in Table 3, the units are divided according to the default length.

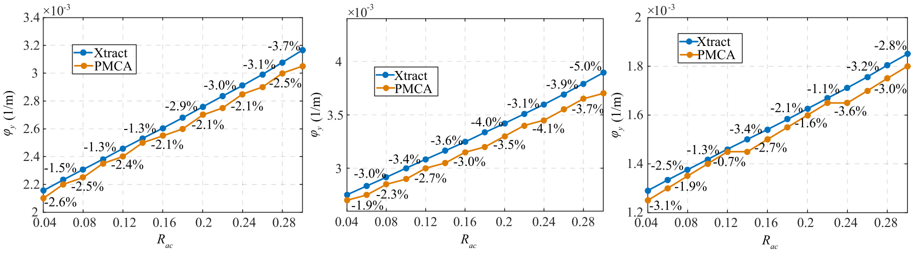
4.2 Comparison

By applying Xtract and PMCA, the yield curvature of all conditions in Table 3 is calculated and compared. On the one hand, the trend of yield curvature with the change of R_{ac} can be seen. On the other hand, Xtract can be set as the control group to verify the accuracy of PMCA. The comparison results are shown in Fig. 5. The error rate = 100% × (PMCA—Xtract) / Xtract.

From the comparison of the two, the above two problems can be easily solved: (1) With the increase of R_{ac}, the yield curvature also increases, which is roughly a linear relationship; (2) The calculation results of PMCA and Xtract are very close, the error between the two is about 3%, and the maximum is only 5%. Therefore, PMCA can replace Xtract

Table 3 Parameters information

Test	L (m)	f_y (MPa)	Lower level of R_{ac}	Upper level of R_{ac}	Increment
1	1.2	360	0.04	0.30	0.02
2	1.2	460			
3	2.0	360			



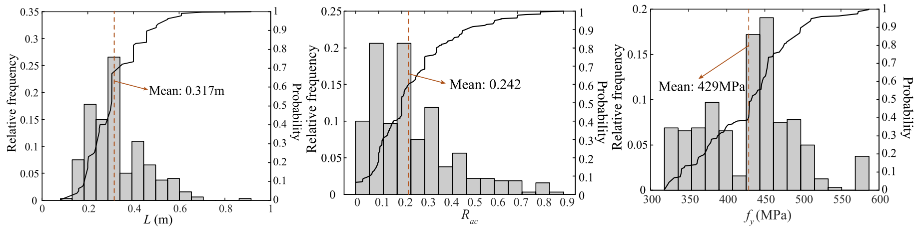
(a) (b) (c)

Fig. 5 Comparison between specification and numerical simulation: **a** Test 1; **b** Test 2; and **c** Test 3 as the main tool to obtain yield curvature in the follow study. In addition, considering that the influence of longitudinal steel bars into ‘steel loop’, the yield curvature of PMCA is always smaller than Xtract. However, this is beneficial to engineering design and can leave a certain safety space for the project.

5 Experimental data

The experiment of PEER database is integrated here (Nagasaka 1982; Imai and Yamamoto 1986; Zhou et al. 1987; Arakawa et al. 1989; Umehara 1983; Bett et al. 1985; Aboutaha et al. 1999; Iwasaki et al. 1985; Priestley et al. 1994; Pandey and Mutsuyoshi 2005; Yoshimura et al. 1991; Hassane 2002; Nakamura and Yoshimura 2002; Moehle 2000; Wight 1973; Lynn et al. 1996; Pandey and Mutsuyoshi 2005; Nagasaka 1982; Ohue et al. 1985; Ono and Shimizu 1985; Ono 1989; Amitsu et al. 1991; Wight 1973; Lynn et al. 1996; Xiao and Martirossyan 1998; Sezen and Moehle 2002; Iwasaki et al. 1985; Ikeda 1968; Umemura and Endo 1970; Hirosawa 1973; Yalcin 1997; Elwood and Moehle 2008; Saatcioglu and Ozcebe 1989; Esaki 1996; Lynn et al. 1996; Yoshimura et al. 2003; Yarandi 2007; Pandey and Mutsuyoshi 2005; Yoshimura and Yamanaka 2000; Gill 1979; Ang 1981; Soesianawati 1986; Zahn 1985; Watson 1989; Tanaka 1990; Park and Paulay 1990; Arakawa et al. 1982; Ohno and Nishioka 1984; Zhou et al. 1987; Kanda 1988; Muguruma et al. 1989; Sakai 1990; Atalay and Penzien 1975; Azizinamini et al. 1988; Saatcioglu and Ozcebe 1989; Galeota et al. 1996; Wehbe 1998; Xiao and Martirossyan 1998; Sugano 1996; Nosho et al. 1996; Bayrak and Sheikh 1996; Saatcioglu and Grira 1999; Matamoros 1999; Mo and Wang 2000; Aboutaha and Machado 1999; Thomson and Wallace 1994; Legeron and Paultre 2000; Paultre et al. 2001; Pujol 2002; Kono and Watanabe 2000; Harries et al. 2006; Melek and Wallace 2004). The distribution of L, R_{ac} and f_y are represented by the histogram and the cumulative probability, as shown in Fig. 6. It can be seen that L and R_{ac} are roughly logarithmic normal distribution, with mean values of 0.317m and 0.242, respectively, while f_y is roughly uniform distribution, with mean value of 429MPa.

The research object of this paper is mainly the bridge column with flexural failure. In order to ensure that the bridge column is flexural failure, only the shear span ratio not less than 2.5 (H/L$\geq$2.5) and the square section bridge column of ordinary reinforced concrete are retained. Therefore, the stacked bar charts for the column physical parameters are shown in Fig. 7, f_{yh} is the yield strength of stirrups; H/L is the column aspect ratio.



(a) (b) (c)

Fig. 6 The experimental columns parameter distribution of PEER database: **a** L; **b** R_{ac}; **c** f_y

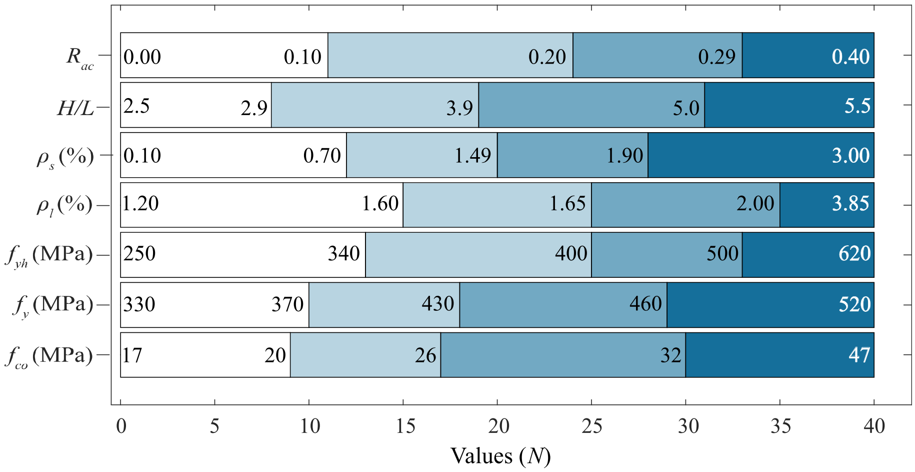


Fig. 7 Stacked bar chart of column physical parameters

According to the yield displacement method proposed by Priestley and Park (Eq. 3), the yield displacement of these experiments is marked in the hysteresis curve, and the results are shown in Fig. 8.

$$\Delta_y = \frac{\varphi_y H^2}{3} \Rightarrow \varphi_y = \frac{3\Delta_y}{H^2} \tag{3}$$

6 Prediction model combined with Chinese specification

6.1 New prediction model

Considering that the effective yield curvature is close to the yield curvature, so the prediction model of yield curvature is derived based on the effective yield curvature prediction model of Chinese specification. Based on the accuracy of PMCA, and this study removes some less influential parameters to use easily, a new prediction model is proposed which combines the exponential function considering the influence of R_{ac} with the Chinese specification. A large number of levels are obtained by PMCA, the parameters information is shown in Table 2. The new prediction model is not complex and is more suitable for researchers to use directly. The prediction model is as follows:

$$\varphi_y = 1.957\frac{f_y}{L \times E_s} \times b_1(1 - R_{ac})^{b_2} \tag{4}$$

where the first part is the Chinese specification effective yield curvature prediction model, b_1 and b_2 are the coefficients. The values of b_1 and b_2 are fitted by the least square method. Finally, the prediction model of ϕ_y combined with Chinese specification is Eq. 5. The experimental axial compression ratios of the retained PEER database are all brought into the new prediction model, and the average value of the coefficients is calculated, the coefficient is 1.82, it shows that the yield curvature is about 0.1 times smaller than the coefficient of effective yield curvature (1.957).

$$\varphi_y = 1.449\frac{f_y}{L \times E_s \times (1 - R_{ac})} \tag{5}$$

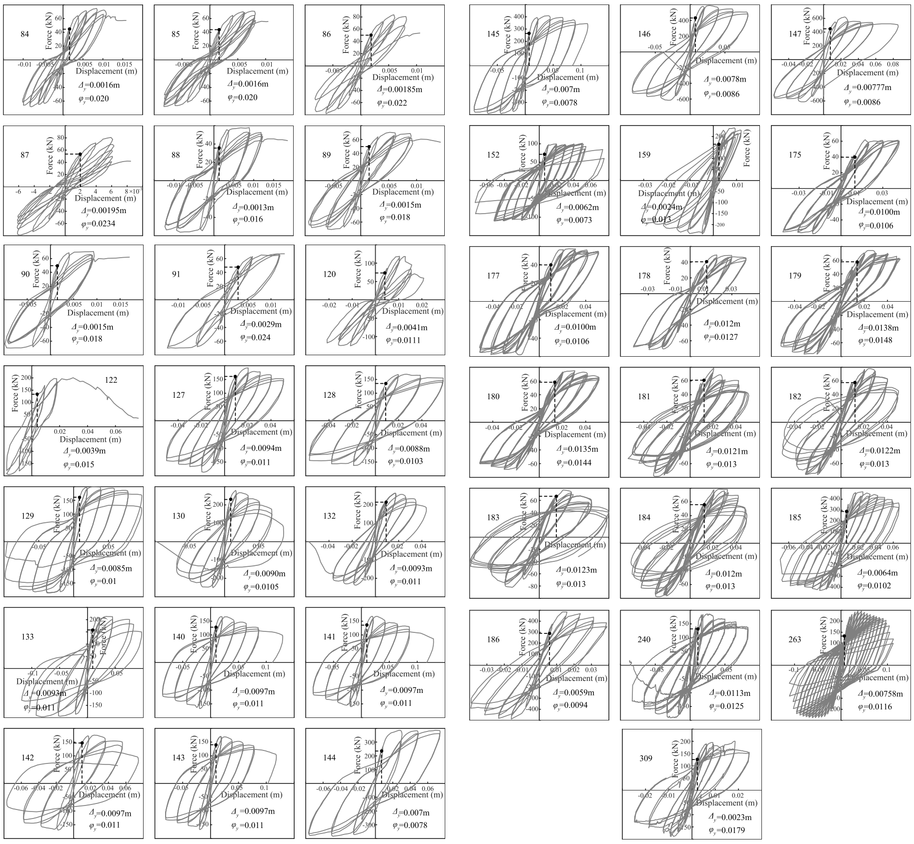


Fig. 8 Yield displacement and yield curvature of experiment

6.2 Application of the prediction model

In order to verify the accuracy of the new prediction model, the yield curvature obtained from the experiment is compared with the predicted, and the results are shown in the Table 4 and Fig. 9.

From the comparison in Fig. 9 and Table 4, it can be seen that the results of the experiment and the prediction are very close, and the error rate is kept within -20% ~ 20%, and most of them are less than 0%. This shows that the predicted yield curvature is often smaller than the experiment, which also provides a certain safety space for practical projects. In addition, the reason why some errors are relatively large may be that the data source of the new prediction model is determined according to the set condition range. There will be some errors outside the range, but the error is still guaranteed to be within a relatively small range. Therefore, the prediction model can be used to predict the yield curvature of practical engineering.

7 Conclusions

The main purpose of this paper is to study the influence of axial compression ratio on yield curvature, and propose a prediction model considering the axial compression ratio based on the effective yield curvature prediction model of Chinese specification.

Table 4 The comparison between experiment and new model

#	Reference	R_{ac}	L (m)	f_y (MPa)	Experiment	New model	EN (%)
84	Iwasaki et al. 1985)	0.10	0.20	434	0.01977	0.01747	-11.6
85	Ikeda 1968)	0.10	0.20	434	0.01977	0.01747	-11.6
86	Ikeda 1968)	0.20	0.20	434	0.02219	0.01966	-11.4
87	Ikeda 1968)	0.20	0.20	434	0.02335	0.01966	-15.8
88	Ikeda 1968)	0.10	0.20	345	0.01568	0.01389	-11.4
89	Ikeda 1968)	0.20	0.20	345	0.01796	0.01563	-13.0
90	Ikeda 1968)	0.20	0.20	345	0.01796	0.01563	-13.0
91	Ikeda 1968)	0.22	0.20	462	0.02434	0.02154	-11.5
120	Pandey and Mutsuyoshi 2005)	0.03	0.30	396	0.01110	0.00983	-11.4
122	Yoshimura and Yamanaka 2000)	0.26	0.30	387	0.01457	0.01263	-13.3
127	Ang 1981)	0.38	0.40	427	0.01098	0.01248	13.6
128	Ang 1981)	0.21	0.40	427	0.01037	0.00979	-5.6
129	Soesianawati 1986)	0.10	0.40	446	0.01000	0.00898	-10.2
130	Soesianawati 1986)	0.30	0.40	446	0.01050	0.01154	9.9
132	Soesianawati 1986)	0.30	0.40	446	0.01087	0.01154	6.2
133	Zahn 1985)	0.22	0.40	440	0.01086	0.01026	-5.5
140	Tanaka 1990)	0.20	0.40	474	0.01133	0.01073	-5.3
141	Tanaka 1990)	0.20	0.40	474	0.01133	0.01073	-5.3
142	Tanaka 1990)	0.20	0.40	474	0.01133	0.01073	-5.3
143	Tanaka 1990)	0.20	0.40	474	0.01133	0.01073	-5.3
144	Tanaka 1990)	0.10	0.55	511	0.00776	0.00748	-3.6
145	Tanaka 1990)	0.10	0.55	511	0.00776	0.00748	-3.6
146	Tanaka 1990)	0.30	0.55	511	0.00856	0.00963	12.5
147	Tanaka 1990)	0.30	0.55	511	0.00856	0.00962	12.3
152	Ohno and Nishioka 1984)	0.03	0.40	362	0.00731	0.00677	-7.3
159	Kanda 1988)	0.11	0.25	374	0.01288	0.01212	-5.9
175	Atalay and Penzien 1975)	0.10	0.31	367	0.01064	0.00967	-9.1
177	Atalay and Penzien 1975)	0.10	0.31	367	0.01067	0.00967	-9.4
178	Atalay and Penzien 1975)	0.10	0.31	429	0.01273	0.01137	-10.7
179	Atalay and Penzien 1975)	0.20	0.31	429	0.01479	0.01266	-14.4
180	Atalay and Penzien 1975)	0.18	0.31	429	0.01443	0.01244	-13.8
181	Atalay and Penzien 1975)	0.26	0.31	363	0.01293	0.01163	-10.0
182	Atalay and Penzien 1975)	0.27	0.31	363	0.01298	0.01174	-9.5
183	Atalay and Penzien 1975)	0.28	0.31	363	0.01315	0.01194	-9.2
184	Atalay and Penzien 1975)	0.27	0.31	363	0.01304	0.01183	-9.3
185	Azizinamini et al. 1988)	0.21	0.46	439	0.01021	0.00876	-14.2
186	Azizinamini et al. 1988)	0.31	0.46	439	0.00940	0.01009	7.3
240	Saatcioglu and Grira 1999)	0.20	0.35	455	0.01249	0.01177	-5.8
263	Mo and Wang 2000)	0.11	0.40	497	0.01160	0.01013	-12.7
309	Kono and Watanabe 2000)	0.30	0.25	461	0.01790	0.01909	6.6

EN:100% × (New model—Experiment)/ Experiment

To achieve this goal, parametric moment–curvature curves approach (PMCA) is adopted to verify that section size, the yield strength of longitudinal steel bar and the axial compression ratio have great influence on yield curvature. Then, some levels under different section size, the yield strength of longitudinal steel bar and the axial compression ratio were set, and the yield curvature was obtained by Xtract

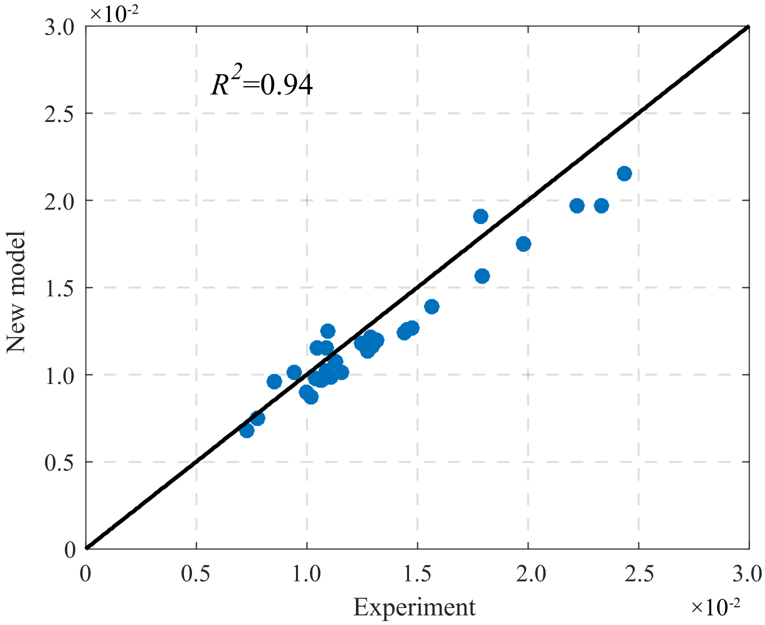


Fig. 9 Comparison between experiment and new model

and PMCA and compared, the result shows that the yield curvature increases with the increase of the axial compression ratio. Besides, a new prediction model is proposed by combining the exponential function with effective yield curvature prediction model of Chinese specification, the yield curvature of the database of PEER is compared with the new prediction model. Through the above research, the following conclusions can be obtained:

(1) The numerical simulation result shows that yield curvature increases with the increase of the axial compression ratio, and the growth trend is obvious, which is different from the specifications effective yield curvature prediction model.
(2) The yield curvature prediction model proposed in this study can well predict the yield curvature of the experiment, and the error is between -20% and 20%, and most of them are concentrated near -10%. The negative error indicates that the prediction is smaller than the experiment, indicating that retaining a certain safety space and it is beneficial to the actual project.

In this paper, a simplified prediction model of yield curvature is proposed, which provides a convenient tool for the design of bridge columns in practical engineering. However, this paper only studies the square cross-section column and cannot predict the curvature of the limit state after the column yield. In the future research, we will make up for these deficiencies.

8 Appendix

#	Reference	ID	f_c (MPa)	f_y (MPa)	f_{yh} (MPa)	L (m)	W (m)	R_{ac}	ρ_l (%)	ρ_s (%)
1	Nagasaka 1982)	HPRC10-63	21.6	371	344	0.20	0.20	0.17	1.27	0.80
2	Imai and Yamamoto 1986)	UNIT_1	27.1	318	336	0.50	0.40	0.07	2.66	0.40
3	Zhou et al. 1987)	No.104–08	19.8	341	559	0.16	0.16	0.80	2.22	0.70
4	Zhou et al. 1987)	No.114–08	19.8	341	559	0.16	0.16	0.80	2.22	0.70
5	Zhou et al. 1987)	No.124–08	19.8	341	559	0.16	0.16	0.80	2.22	1.80
6	Arakawa et al. 1989)	OA2	31.8	340	249	0.18	0.18	0.18	3.13	0.20
7	Arakawa et al. 1989)	OA5	33.0	340	249	0.18	0.18	0.45	3.13	0.20
8	Umehara 1983)	CUS	34.9	441	414	0.41	0.23	0.16	3.01	0.30
9	Umehara 1983)	CUW	34.9	441	414	0.23	0.41	0.16	3.01	0.30
10	Bett et al. 1985)	UNIT_1_1	29.9	462	414	0.31	0.31	0.10	2.44	0.30
11	Aboutaha et al. 1999)	SC3	21.9	434	400	0.46	0.91	0.00	1.88	0.27
12	Aboutaha et al. 1999)	SC9	16.0	434	400	0.91	0.46	0.00	1.88	0.20
13	Iwasaki et al. 1985)	I18	33.1	323	258	0.50	0.50	0.00	2.12	0.47
14	Iwasaki et al. 1985)	I21	31.7	323	258	0.50	0.50	0.00	2.12	0.47
15	Priestley et al. 1994)	UnitR3A	34.5	469	324	0.41	0.61	0.06	2.53	0.23
16	Priestley et al. 1994)	UnitR5A	32.4	469	324	0.41	0.61	0.06	2.53	0.23
17	Priestley et al. 1994)	Specimen_B1	32.5	380	396	0.30	0.30	0.03	2.68	0.18
18	Pandey and Mutsuyoshi 2005)	Specimen_CE	26.0	388	312	0.18	0.18	0.10	3.08	0.70
19	Yoshimura et al. 1991)	Specimen_BE	32.7	344	312	0.18	0.18	0.10	3.08	0.70
20	Yoshimura et al. 1991)	Specimen_LE	41.5	344	322	0.18	0.18	0.10	6.94	3.78
21	Yoshimura et al. 1991)	No.1	30.7	402	392	0.30	0.30	0.20	2.68	0.47
22	Yoshimura et al. 1991)	No.3	30.7	402	392	0.30	0.30	0.20	2.68	0.24
23	Yoshimura et al. 1991)	No.4	30.7	402	392	0.30	0.30	0.30	2.68	0.47
24	Yoshimura et al. 1991)	C1	13.5	340	587	0.30	0.30	0.30	1.69	0.20
25	Hassane 2002)	C4	13.5	340	587	0.30	0.30	0.30	1.69	0.69
26	Hassane 2002)	C8	18.0	340	384	0.30	0.30	0.30	1.69	0.69
27	Hassane 2002)	C12	18.0	340	384	0.30	0.30	0.20	1.69	0.69
28	Hassane 2002)	D1	27.7	447	398	0.30	0.30	0.22	1.69	1.03
29	Hassane 2002)	D11	28.1	447	398	0.30	0.30	0.21	2.25	0.34
30	Hassane 2002)	D12	28.1	447	398	0.30	0.30	0.21	2.25	0.34
31	Hassane 2002)	D13	26.1	447	398	0.30	0.30	0.23	2.25	1.03
32	Hassane 2002)	D14	26.1	447	398	0.30	0.30	0.23	2.25	1.03
33	Hassane 2002)	D16	26.1	447	398	0.30	0.30	0.23	1.69	1.03
34	Hassane 2002)	N-18 M	26.5	380	380	0.30	0.30	0.18	2.68	0.53
35	Nakamura and Yoshimura 2002)	N-27C	26.5	380	380	0.30	0.30	0.27	2.68	0.53
36	Nakamura and Yoshimura 2002)	N-27 M	26.5	380	380	0.30	0.30	0.27	2.68	0.53
37	Nakamura and Yoshimura 2002)	S-1	25.1	547	355	0.40	0.40	0.20	3.87	0.45
38	Moehle 2000)	WI_0_033E	32.0	496	345	0.31	0.15	0.00	2.45	0.33
39	Wight 1973)	3CLH18	26.9	331	400	0.46	0.46	0.09	3.03	0.16
40	Lynn et al. 1996)	A1	28.8	380	396	0.30	0.30	0.03	2.68	0.30
41	Pandey and Mutsuyoshi 2005)	HPRC19-32	21.0	371	344	0.20	0.20	0.35	1.27	1.40
42	Nagasaka 1982)	2D16RS	32.0	369	316	0.20	0.20	0.14	2.01	0.60
43	Ohue et al. 1985)	4D13RS	29.9	370	316	0.20	0.20	0.15	2.65	0.60
44	Ohue et al. 1985)	No.1007	34.0	336	341	0.08	0.08	0.70	1.77	0.50
45	Ono and Shimizu 1985)	No.204–08	21.1	341	559	0.16	0.16	0.80	2.22	0.70
46	Ono and Shimizu 1985)	No.223–09	21.1	341	559	0.16	0.16	0.90	2.22	1.80
47	Ono and Shimizu 1985)	No.302–07	28.8	341	559	0.16	0.16	0.70	2.22	0.70

#	Reference	ID	f_c (MPa)	f_y (MPa)	f_{yh} (MPa)	L (m)	W (m)	R_{ac}	ρ_l (%)	ρ_s (%)
48	Ono and Shimizu 1985)	No.312–07	28.8	341	559	0.16	0.16	0.70	2.22	0.70
49	Ono and Shimizu 1985)	CA025C	25.8	361	426	0.20	0.20	0.26	2.13	0.90
50	Ono 1989)	CA060C	25.8	361	426	0.20	0.20	0.62	2.13	0.90
51	Ono 1989)	CB060C	46.3	441	414	0.28	0.28	0.74	2.75	0.90
52	Amitsu et al. 1991)	WI_40_033aE	34.7	496	345	0.31	0.15	0.12	2.45	0.33
53	Wight 1973)	WI_40_033aW	34.7	496	345	0.31	0.15	0.12	2.45	0.33
54	Wight 1973)	WI_40_048E	26.1	496	345	0.31	0.15	0.15	2.45	0.48
55	Wight 1973)	WI_40_048W	26.1	496	345	0.31	0.15	0.15	2.45	0.48
56	Wight 1973)	WI_40_033_E	33.6	496	345	0.31	0.15	0.11	2.45	0.33
57	Wight 1973)	WI_40_033_W	33.6	496	345	0.31	0.15	0.11	2.45	0.33
58	Wight 1973)	WI_25_033_E	33.6	496	345	0.31	0.15	0.07	2.45	0.33
59	Wight 1973)	WI_25_033_W	33.6	496	345	0.31	0.15	0.07	2.45	0.33
60	Wight 1973)	WI_0_048W	25.9	496	345	0.31	0.15	0.00	2.45	0.48
61	Wight 1973)	WI_40_067_E	33.4	496	345	0.31	0.15	0.11	2.45	0.70
62	Wight 1973)	WI_40_067_W	33.4	496	345	0.31	0.15	0.11	2.45	0.70
63	Wight 1973)	WI_40_147_E	33.5	496	317	0.31	0.15	0.11	2.45	1.50
64	Wight 1973)	WI_40_147_W	33.5	496	317	0.31	0.15	0.11	2.45	1.50
65	Wight 1973)	WI_40_092_E	33.5	496	317	0.31	0.15	0.11	2.45	0.90
66	Wight 1973)	WI_40_092_W	33.5	496	317	0.31	0.15	0.11	2.45	0.90
67	Wight 1973)	2CLH18	33.1	331	400	0.46	0.46	0.07	1.94	0.16
68	Lynn et al. 1996)	2CMH18	25.5	331	400	0.46	0.46	0.28	1.94	0.16
69	Lynn et al. 1996)	2SLH18	33.1	331	400	0.46	0.46	0.07	1.94	0.16
70	Lynn et al. 1996)	3SMD12	25.5	331	400	0.46	0.46	0.28	3.03	0.41
71	Lynn et al. 1996)	HC4-0.1P	86.0	510	449	0.25	0.25	0.10	2.46	1.60
72	Xiao and Martirossyan 1998a)	HC4-0.2P	86.0	510	449	0.25	0.25	0.19	2.46	1.60
73	Xiao and Martirossyan 1998a)	Specimen_1	21.1	434	476	0.46	0.46	0.15	2.48	0.20
74	Sezen and Moehle 2002)	Specimen_2	21.1	434	476	0.46	0.46	0.61	2.48	0.20
75	Sezen and Moehle 2002)	Specimen_4	21.8	434	476	0.46	0.46	0.15	2.48	0.20
76	Sezen and Moehle 2002)	I_03	30.7	323	258	0.40	0.80	0.00	1.42	0.61
77	Iwasaki et al. 1985)	I_04	28.4	323	258	0.40	0.80	0.00	1.77	0.61
78	Iwasaki et al. 1985)	I_10	31.2	323	258	0.50	0.50	0.00	2.12	0.47
79	Iwasaki et al. 1985)	I_14	32.0	323	258	0.50	0.50	0.00	2.12	0.47
80	Iwasaki et al. 1985)	I_16	31.8	323	258	0.50	0.50	0.00	2.12	0.47
81	Iwasaki et al. 1985)	I_17	31.8	323	258	0.50	0.50	0.00	2.12	0.47
82	Iwasaki et al. 1985)	I_20	33.3	323	258	0.50	0.50	0.00	2.12	0.47
83	Iwasaki et al. 1985)	I_25	33.0	323	258	0.50	0.50	0.00	2.12	2.37
84	Iwasaki et al. 1985)	IK_43	19.6	434	559	0.20	0.20	0.10	1.99	0.66
85	Ikeda 1968)	IK_44	19.6	434	559	0.20	0.20	0.10	1.99	0.66
86	Ikeda 1968)	IK_45	19.6	434	559	0.20	0.20	0.20	1.99	0.66
87	Ikeda 1968)	IK_46	19.6	434	559	0.20	0.20	0.20	2.66	0.66
88	Ikeda 1968)	IK_62	19.6	345	476	0.20	0.20	0.10	1.97	0.67
89	Ikeda 1968)	IK_63	19.6	345	476	0.20	0.20	0.20	1.97	0.67
90	Ikeda 1968)	IK_64	19.6	345	476	0.20	0.20	0.20	1.97	0.67
91	Ikeda 1968)	UM_205	17.6	462	324	0.20	0.20	0.22	1.99	0.61
92	Umemura and Endo 1970)	UM_207	17.6	462	324	0.20	0.20	0.22	1.99	0.61
93	Umemura and Endo 1970)	UM_214	17.6	462	324	0.20	0.20	0.56	1.99	0.31
94	Umemura and Endo 1970)	UM_220	32.9	379	648	0.20	0.20	0.12	1.18	0.24
95	Umemura and Endo 1970)	UM_231	14.8	324	524	0.20	0.20	0.27	0.95	0.28
96	Umemura and Endo 1970)	UM_232	13.1	324	524	0.20	0.20	0.30	0.95	0.28
97	Umemura and Endo 1970)	UM_233	13.9	372	524	0.20	0.20	0.28	1.18	0.28

#	Reference	ID	f_c (MPa)	f_y (MPa)	f_{yh} (MPa)	L (m)	W (m)	R_{ac}	ρ_l (%)	ρ_s (%)
98	Umemura and Endo 1970)	UM_234	13.1	372	524	0.20	0.20	0.30	1.18	0.28
99	Umemura and Endo 1970)	KO_372	19.9	524	352	0.20	0.20	0.20	1.33	0.80
100	Hirosawa 1973)	KO_373	20.4	524	352	0.20	0.20	0.19	1.98	0.79
101	Hirosawa 1973)	KO_452	21.9	359	316	0.20	0.20	0.45	2.84	0.77
102	Hirosawa 1973)	KO_454	21.9	359	316	0.20	0.20	0.45	3.80	0.76
103	Hirosawa 1973)	BR-S1	45.0	445	425	0.55	0.55	0.13	1.98	0.30
104	Yalcin 1997)	Specimen1	24.5	479	718	0.23	0.23	0.10	1.94	0.45
105	Elwood and Moehle 2008)	Specimen2	23.9	479	718	0.23	0.23	0.24	1.94	0.45
106	Elwood and Moehle 2008)	UnitR1A	37.9	324	359	0.61	0.41	0.05	2.53	0.23
107	Saatcioglu and Ozcebe 1989)	U2	30.2	453	470	0.35	0.35	0.16	3.21	0.69
108	Esaki 1996)	H-2-1_3	23.0	362	364	0.20	0.20	0.35	2.65	1.62
109	Esaki 1996)	H-2-1_5	23.0	362	364	0.20	0.20	0.21	2.65	1.29
110	Esaki 1996)	HT-2-1_3	20.2	362	364	0.20	0.20	0.35	2.65	1.62
111	Esaki 1996)	HT-2-1_5	20.2	362	364	0.20	0.20	0.21	2.65	1.29
112	Lynn et al. 1996)	3CMH18	27.6	331	400	0.46	0.46	0.26	3.04	0.16
113	Lynn et al. 1996)	3CMD12	27.6	331	400	0.46	0.46	0.26	3.04	0.42
114	Lynn et al. 1996)	3SLH18	26.9	331	400	0.46	0.46	0.09	3.03	0.16
115	Yoshimura et al. 2003)	Unit_6	30.7	409	392	0.30	0.30	0.20	1.77	0.48
116	Yoshimura et al. 2003)	Unit_7	30.7	409	392	0.30	0.30	0.20	1.77	0.32
117	Yarandi 2007)	RRC	35.0	400	400	0.70	0.35	0.15	1.46	0.11
118	Yarandi 2007)	SRC	42.0	400	400	0.70	0.35	0.15	1.46	0.37
119	Pandey and Mutsuyoshi 2005)	A4	33.1	380	396	0.30	0.30	0.03	2.68	0.65
120	Pandey and Mutsuyoshi 2005)	C1	36.4	396	427	0.30	0.30	0.03	2.68	0.30
121	Yoshimura and Yamanaka 2000)	FS0	27.0	387	355	0.30	0.30	0.26	3.82	1.48
122	Yoshimura and Yamanaka 2000)	FS1	27.0	387	355	0.30	0.30	0.26	3.82	1.48
123	Gill 1979)	No.1	23.1	375	297	0.55	0.55	0.26	1.79	1.50
124	Gill 1979)	No.2	41.4	375	316	0.55	0.55	0.21	1.79	2.30
125	Gill 1979)	No.3	21.4	375	297	0.55	0.55	0.42	1.79	2.00
126	Gill 1979)	No.4	23.5	375	294	0.55	0.55	0.60	1.79	3.50
127	Ang 1981)	No.3	23.6	427	320	0.40	0.40	0.38	1.51	2.80
128	Ang 1981)	No.4	25.0	427	280	0.40	0.40	0.21	1.51	2.20
129	Soesianawati 1986)	No.1	46.5	446	364	0.40	0.40	0.10	1.51	0.90
130	Soesianawati 1986)	No.2	44.0	446	360	0.40	0.40	0.30	1.51	1.20
131	Soesianawati 1986)	No.3	44.0	446	364	0.40	0.40	0.30	1.51	0.80
132	Soesianawati 1986)	No.4	40.0	446	255	0.40	0.40	0.30	1.51	0.60
133	Zahn 1985)	No.7	28.3	440	466	0.40	0.40	0.22	1.51	1.60
134	Zahn 1985)	No.8	40.1	440	466	0.40	0.40	0.39	1.51	2.00
135	Watson 1989)	No.5	41.0	474	372	0.40	0.40	0.50	1.51	0.70
136	Watson 1989)	No.6	40.0	474	388	0.40	0.40	0.50	1.51	0.30
137	Watson 1989)	No.7	42.0	474	308	0.40	0.40	0.70	1.51	1.30
138	Watson 1989)	No.8	39.0	474	372	0.40	0.40	0.70	1.51	0.70
139	Watson 1989)	No.9	40.0	474	308	0.40	0.40	0.70	1.51	2.50
140	Tanaka 1990)	No1	25.6	474	333	0.40	0.40	0.20	1.57	2.50
141	Tanaka 1990)	No2	25.6	474	333	0.40	0.40	0.20	1.57	2.50
142	Tanaka 1990)	No3	25.6	474	333	0.40	0.40	0.20	1.57	2.50
143	Tanaka 1990)	No4	25.6	474	333	0.40	0.40	0.20	1.57	2.50
144	Tanaka 1990)	No5	32.0	511	325	0.55	0.55	0.10	1.25	1.70
145	Tanaka 1990)	No6	32.0	511	325	0.55	0.55	0.10	1.25	1.70
146	Tanaka 1990)	No7	32.0	511	325	0.55	0.55	0.30	1.25	2.10
147	Tanaka 1990)	No8	32.1	511	325	0.55	0.55	0.30	1.25	2.10

#	Reference	ID	f_c (MPa)	f_y (MPa)	f_{yh} (MPa)	L (m)	W (m)	R_{ac}	ρ_l (%)	ρ_s (%)
148	Park and Paulay 1990)	No9	26.9	432	305	0.60	0.40	0.10	1.89	1.88
149	Arakawa et al. 1982)	No.102	20.6	393	323	0.25	0.25	0.33	0.68	1.20
150	Ohno and Nishioka 1984)	L1	24.8	362	325	0.40	0.40	0.03	1.42	0.30
151	Ohno and Nishioka 1984)	L2	24.8	362	325	0.40	0.40	0.03	1.42	0.30
152	Ohno and Nishioka 1984)	L3	24.8	362	325	0.40	0.40	0.03	1.42	0.30
153	Zhou et al. 1987)	214–08	21.1	341	559	0.16	0.16	0.80	2.22	0.70
154	Kanda 1988)	85STC-1	27.9	374	506	0.25	0.25	0.11	1.62	0.40
155	Kanda 1988)	85STC-2	27.9	374	506	0.25	0.25	0.11	1.62	0.40
156	Kanda 1988)	85STC-3	27.9	374	506	0.25	0.25	0.11	1.62	0.40
157	Kanda 1988)	85PDC-1	24.8	374	352	0.25	0.25	0.12	1.62	0.40
158	Kanda 1988)	85PDC-2	27.9	374	506	0.25	0.25	0.11	1.62	0.40
159	Kanda 1988)	85PDC-3	27.9	374	506	0.25	0.25	0.11	1.62	0.40
160	Muguruma et al. 1989)	AL-1	85.7	399	328	0.20	0.20	0.40	3.17	1.60
161	Muguruma et al. 1989)	AH-1	85.7	399	792	0.20	0.20	0.40	3.80	1.60
162	Muguruma et al. 1989)	AL-2	85.7	399	328	0.20	0.20	0.63	3.80	1.60
163	Muguruma et al. 1989)	AH-2	85.7	399	792	0.20	0.20	0.63	3.80	1.60
164	Muguruma et al. 1989)	BL-1	115.8	399	328	0.20	0.20	0.25	3.80	1.60
165	Muguruma et al. 1989)	BH-1	115.8	399	792	0.20	0.20	0.25	3.80	1.60
166	Muguruma et al. 1989)	BL-2	115.8	399	328	0.20	0.20	0.42	3.80	1.60
167	Muguruma et al. 1989)	BH-2	115.8	399	792	0.20	0.20	0.42	3.80	1.60
168	Sakai 1990)	B1	99.5	379	774	0.25	0.25	0.35	2.43	0.50
169	Sakai 1990)	B2	99.5	379	774	0.25	0.25	0.35	2.43	0.70
170	Sakai 1990)	B3	99.5	379	344	0.25	0.25	0.35	2.43	0.60
171	Sakai 1990)	B4	99.5	379	1126	0.25	0.25	0.35	2.43	0.50
172	Sakai 1990)	B5	99.5	379	774	0.25	0.25	0.35	2.43	0.50
173	Sakai 1990)	B6	99.5	379	857	0.25	0.25	0.35	2.43	0.50
174	Sakai 1990)	B7	99.5	339	774	0.25	0.25	0.35	1.81	0.50
175	Atalay and Penzien 1975)	No.1S1	29.1	367	363	0.31	0.31	0.10	1.63	1.50
176	Atalay and Penzien 1975)	No.2S1	30.7	367	363	0.31	0.31	0.09	1.63	0.90
177	Atalay and Penzien 1975)	No.3S1	29.2	367	363	0.31	0.31	0.10	1.63	1.50
178	Atalay and Penzien 1975)	No.4S1	27.6	429	363	0.31	0.31	0.10	1.63	0.90
179	Atalay and Penzien 1975)	No.5S1	29.4	429	392	0.31	0.31	0.20	1.63	1.50
180	Atalay and Penzien 1975)	No.6S1	31.8	429	392	0.31	0.31	0.18	1.63	0.90
181	Atalay and Penzien 1975)	No.9	33.3	363	392	0.31	0.31	0.26	1.63	1.50
182	Atalay and Penzien 1975)	No.10	32.4	363	392	0.31	0.31	0.27	1.63	0.90
183	Atalay and Penzien 1975)	No.11	31.0	363	373	0.31	0.31	0.28	1.63	1.50
184	Atalay and Penzien 1975)	No.12	31.8	363	373	0.31	0.31	0.27	1.63	0.90
185	Azizinamini et al. 1988)	NC	39.3	439	454	0.46	0.46	0.21	1.94	2.20
186	Azizinamini et al. 1988)	NC	39.8	439	616	0.46	0.46	0.31	1.94	1.30
187	Saatcioglu and Ozcebe 1989)	U1	43.6	430	470	0.35	0.35	0.00	3.31	0.90
188	Saatcioglu and Ozcebe 1989)	U3	34.8	430	470	0.35	0.35	0.14	3.31	2.50
189	Saatcioglu and Ozcebe 1989)	U4	32.0	438	470	0.35	0.35	0.15	3.31	2.50
190	Saatcioglu and Ozcebe 1989)	U6	37.3	437	425	0.35	0.35	0.13	3.31	3.21
191	Saatcioglu and Ozcebe 1989)	U7	39.0	437	425	0.35	0.35	0.13	3.31	2.00
192	Galeota et al. 1996)	AA1	80.0	430	430	0.25	0.25	0.30	1.51	1.20
193	Galeota et al. 1996)	AA2	80.0	430	430	0.25	0.25	0.30	1.51	1.20
194	Galeota et al. 1996)	AA3	80.0	430	430	0.25	0.25	0.20	1.51	1.20
195	Galeota et al. 1996)	AA4	80.0	430	430	0.25	0.25	0.20	1.51	1.20
196	Galeota et al. 1996)	BA1	80.0	430	430	0.25	0.25	0.20	1.51	1.80
197	Galeota et al. 1996)	BA2	80.0	430	430	0.25	0.25	0.30	1.51	1.80

#	Reference	ID	f_c (MPa)	f_y (MPa)	f_{yh} (MPa)	L (m)	W (m)	R_{ac}	ρ_l (%)	ρ_s (%)
198	Galeota et al. 1996)	BA3	80.0	430	430	0.25	0.25	0.30	1.51	1.80
199	Galeota et al. 1996)	BA4	80.0	430	430	0.25	0.25	0.20	1.51	1.80
200	Galeota et al. 1996)	CA1	80.0	430	430	0.25	0.25	0.20	1.51	3.70
201	Galeota et al. 1996)	CA2	80.0	430	430	0.25	0.25	0.30	1.51	3.70
202	Galeota et al. 1996)	CA3	80.0	430	430	0.25	0.25	0.20	1.51	3.70
203	Galeota et al. 1996)	CA4	80.0	430	430	0.25	0.25	0.30	1.51	3.70
204	Galeota et al. 1996)	AB1	80.0	430	430	0.25	0.25	0.20	6.03	1.20
205	Galeota et al. 1996)	AB2	80.0	430	430	0.25	0.25	0.30	6.03	1.20
206	Galeota et al. 1996)	AB3	80.0	430	430	0.25	0.25	0.30	6.03	1.20
207	Galeota et al. 1996)	AB4	80.0	430	430	0.25	0.25	0.20	6.03	1.20
208	Galeota et al. 1996)	BB	80.0	430	430	0.25	0.25	0.20	6.03	1.80
209	Galeota et al. 1996)	BB1	80.0	430	430	0.25	0.25	0.20	6.03	1.80
210	Galeota et al. 1996)	BB4	80.0	430	430	0.25	0.25	0.30	6.03	1.80
211	Galeota et al. 1996)	BB4B	80.0	430	430	0.25	0.25	0.30	6.03	1.80
212	Galeota et al. 1996)	CB1	80.0	430	430	0.25	0.25	0.20	6.03	3.70
213	Galeota et al. 1996)	CB2	80.0	430	430	0.25	0.25	0.20	6.03	3.70
214	Galeota et al. 1996)	CB3	80.0	430	430	0.25	0.25	0.30	6.03	3.70
215	Galeota et al. 1996)	CB4	80.0	430	430	0.25	0.25	0.30	6.03	3.70
216	Wehbe 1998)	A1	27.2	448	428	0.61	0.38	0.10	2.22	0.40
217	Wehbe 1998)	A2	27.2	448	428	0.61	0.38	0.24	2.22	0.40
218	Wehbe 1998)	B1	28.1	448	428	0.61	0.38	0.09	2.22	0.50
219	Wehbe 1998)	B2	28.1	448	428	0.61	0.38	0.23	2.22	0.50
220	Xiao and Martirossyan 1998b)	HC4-0.1P	76.0	510	510	0.25	0.25	0.10	3.55	3.70
221	Xiao and Martirossyan 1998b)	HC4-0.2P	76.0	510	510	0.25	0.25	0.20	3.55	3.70
222	Xiao and Martirossyan 1998b)	HC4-0.1P	86.0	510	510	0.25	0.25	0.10	2.46	3.70
223	Xiao and Martirossyan 1998b)	HC4-0.2P	86.0	510	510	0.25	0.25	0.19	2.46	3.70
224	Sugano 1996)	UC10H	118.0	393	1415	0.23	0.23	0.60	1.86	3.18
225	Sugano 1996)	UC15H	118.0	393	1424	0.23	0.23	0.60	1.86	5.00
226	Sugano 1996)	UC20H	118.0	393	1424	0.23	0.23	0.60	1.86	5.00
227	Sugano 1996)	UC15L	118.0	393	1424	0.23	0.23	0.35	1.86	5.00
228	Sugano 1996)	UC20L	118.0	393	1424	0.23	0.23	0.35	1.86	5.00
229	Nosho et al. 1996)	No.1	40.6	407	351	0.28	0.28	0.34	1.01	2.18
230	Bayrak and Sheikh 1996)	ES-1HT	72.1	454	463	0.31	0.31	0.50	2.58	3.20
231	Bayrak and Sheikh 1996)	AS-2HT	71.7	454	542	0.31	0.31	0.36	2.58	2.80
232	Bayrak and Sheikh 1996)	AS-3HT	71.8	454	542	0.31	0.31	0.50	2.58	2.80
233	Bayrak and Sheikh 1996)	AS-4HT	71.9	454	463	0.31	0.31	0.50	2.58	5.10
234	Bayrak and Sheikh 1996)	AS-5HT	101.8	454	463	0.31	0.31	0.45	2.58	4.00
235	Bayrak and Sheikh 1996)	AS-6HT	101.9	454	463	0.31	0.31	0.46	2.58	6.70
236	Bayrak and Sheikh 1996)	AS-7HT	102.0	454	542	0.31	0.31	0.45	2.58	2.70
237	Bayrak and Sheikh 1996)	ES-8HT	102.2	454	463	0.31	0.31	0.47	2.58	4.30
238	Saatcioglu and Grira 1999)	BG-1	34.0	455	570	0.35	0.35	0.43	1.95	1.00
239	Saatcioglu and Grira 1999)	BG-2	34.0	455	570	0.35	0.35	0.43	1.95	2.00
240	Saatcioglu and Grira 1999)	BG-3	34.0	455	570	0.35	0.35	0.20	1.95	2.00
241	Saatcioglu and Grira 1999)	BG-4	34.0	455	570	0.35	0.35	0.46	2.93	1.30
242	Saatcioglu and Grira 1999)	BG-5	34.0	455	570	0.35	0.35	0.46	2.93	2.70
243	Saatcioglu and Grira 1999)	BG-6	34.0	478	570	0.35	0.35	0.46	2.29	2.70
244	Saatcioglu and Grira 1999)	BG-7	34.0	455	580	0.35	0.35	0.46	2.93	1.30
245	Saatcioglu and Grira 1999)	BG-8	34.0	455	580	0.35	0.35	0.23	2.93	1.30
246	Saatcioglu and Grira 1999)	BG-9	34.0	428	580	0.35	0.35	0.46	3.28	1.30
247	Saatcioglu and Grira 1999)	BG-10	34.0	428	570	0.35	0.35	0.46	3.28	2.70

#	Reference	ID	f_c (MPa)	f_y (MPa)	f_{yh} (MPa)	L (m)	W (m)	R_{ac}	ρ_l (%)	ρ_s (%)
248	Matamoros 1999)	C10-05N	69.6	586	407	0.20	0.20	0.05	1.93	1.00
249	Matamoros 1999)	C10-05S	69.6	586	407	0.20	0.20	0.05	1.93	1.00
250	Matamoros 1999)	C10-10N	67.8	572	514	0.20	0.20	0.10	1.93	1.00
251	Matamoros 1999)	C10-10S	67.8	573	515	0.20	0.20	0.10	1.93	1.00
252	Matamoros 1999)	C10-20N	65.5	572	514	0.20	0.20	0.21	1.93	1.00
253	Matamoros 1999)	C10-20S	65.5	573	515	0.20	0.20	0.21	1.93	1.00
254	Matamoros 1999)	C5-00N	37.9	572	514	0.20	0.20	0.00	1.93	1.00
255	Matamoros 1999)	C5-00S	37.9	573	515	0.20	0.20	0.00	1.93	1.00
256	Matamoros 1999)	C5-20N	48.3	586	407	0.20	0.20	0.14	1.93	1.00
257	Matamoros 1999)	C5-20S	48.3	587	408	0.20	0.20	0.14	1.93	1.00
258	Matamoros 1999)	C5-40N	38.0	572	514	0.20	0.20	0.36	1.93	1.00
259	Matamoros 1999)	C5-40S	38.0	573	515	0.20	0.20	0.36	1.93	1.00
260	Mo and Wang 2000)	C1-1	24.9	497	459	0.40	0.40	0.11	2.14	3.00
261	Mo and Wang 2000)	C1-2	26.7	497	459	0.40	0.40	0.16	2.14	3.00
262	Mo and Wang 2000)	C1-3	26.1	497	459	0.40	0.40	0.22	2.14	3.00
263	Mo and Wang 2000)	C2-1	25.3	497	459	0.40	0.40	0.11	2.14	3.00
264	Mo and Wang 2000)	C2-2	27.1	497	459	0.40	0.40	0.16	2.14	3.00
265	Mo and Wang 2000)	C2-3	26.8	497	459	0.40	0.40	0.21	2.14	3.00
266	Mo and Wang 2000)	C3-1	26.4	497	459	0.40	0.40	0.11	2.14	3.00
267	Mo and Wang 2000)	C3-2	27.5	497	459	0.40	0.40	0.15	2.14	3.00
268	Mo and Wang 2000)	C3-3	26.9	497	459	0.40	0.40	0.21	2.14	3.00
269	Aboutaha and Machado 1999)	ORC1	83.0	414	414	0.51	0.31	0.00	2.53	5.19
270	Aboutaha and Machado 1999)	ORC2	83.0	414	414	0.51	0.31	0.12	2.53	5.19
271	Aboutaha and Machado 1999)	ORC3	83.0	414	414	0.51	0.31	0.16	2.53	5.20
272	Thomson and Wallace 1994)	A1	102.7	517	793	0.15	0.15	0.00	2.45	1.44
273	Thomson and Wallace 1994)	A3	86.3	517	793	0.15	0.15	0.20	2.45	1.44
274	Thomson and Wallace 1994)	B1	87.5	455	793	0.15	0.15	0.00	2.45	1.63
275	Thomson and Wallace 1994)	B2	83.4	455	793	0.15	0.15	0.10	2.45	1.63
276	Thomson and Wallace 1994)	B3	90.0	455	793	0.15	0.15	0.20	2.45	1.63
277	Thomson and Wallace 1994)	C1	67.5	476	1262	0.15	0.15	0.00	2.45	1.63
278	Thomson and Wallace 1994)	C2	74.6	476	1262	0.15	0.15	0.10	2.45	1.63
279	Thomson and Wallace 1994)	C3	81.8	476	1262	0.15	0.15	0.20	2.45	1.63
280	Thomson and Wallace 1994)	D1	75.8	476	1262	0.15	0.15	0.20	2.45	1.63
281	Thomson and Wallace 1994)	D2	87.0	476	1262	0.15	0.15	0.20	2.45	1.63
282	Thomson and Wallace 1994)	D3	71.2	476	1262	0.15	0.15	0.20	2.45	1.63
283	Legeron and Paultre 2000)	1,006,015	92.4	451	391	0.31	0.31	0.14	2.57	9.97
284	Legeron and Paultre 2000)	1,006,025	93.3	430	391	0.31	0.31	0.28	2.57	9.97
285	Legeron and Paultre 2000)	1,006,040	98.2	451	418	0.31	0.31	0.39	2.57	9.97
286	Legeron and Paultre 2000)	10,013,015	94.8	451	391	0.31	0.31	0.14	2.57	9.97
287	Legeron and Paultre 2000)	10,013,025	97.7	430	391	0.31	0.31	0.26	2.57	9.97
288	Legeron and Paultre 2000)	10,013,040	104.3	451	418	0.31	0.31	0.37	2.57	9.97
289	Paultre et al. 2001)	806,040	78.7	446	438	0.31	0.31	0.40	2.57	9.97
290	Paultre et al. 2001)	1,206,040	109.2	446	438	0.31	0.31	0.41	2.57	9.97
291	Paultre et al. 2001)	1,005,540	109.5	446	825	0.31	0.31	0.35	2.57	7.04
292	Paultre et al. 2001)	1,008,040	104.2	446	825	0.31	0.31	0.37	2.57	7.04
293	Paultre et al. 2001)	1,005,552	104.5	446	744	0.31	0.31	0.53	2.57	9.84
294	Paultre et al. 2001)	1,006,052	109.4	446	492	0.31	0.31	0.51	2.57	9.97
295	Pujol 2002)	10–2-3N	33.7	453	411	0.30	0.15	0.09	2.45	0.60
296	Pujol 2002)	10–2-3S	33.7	453	411	0.30	0.15	0.09	2.45	0.60
297	Pujol 2002)	10–3-1.5N	32.1	453	411	0.30	0.15	0.09	2.45	1.96

#	Reference	ID	f_c (MPa)	f_y (MPa)	f_{yh} (MPa)	L (m)	W (m)	R_{ac}	ρ_l (%)	ρ_s (%)
298	Pujol 2002)	10–3-1.5S	32.1	453	411	0.30	0.15	0.09	2.45	1.96
299	Pujol 2002)	10–3-3N	29.9	453	411	0.30	0.15	0.10	2.45	1.96
300	Pujol 2002)	10–3-3S	29.9	453	411	0.30	0.15	0.10	2.45	1.96
301	Pujol 2002)	10–3-2.25N	27.4	453	411	0.30	0.15	0.10	2.45	1.96
302	Pujol 2002)	10–3-2.25S	27.4	453	411	0.30	0.15	0.10	2.45	1.96
303	Pujol 2002)	20–3-3N	36.4	453	411	0.30	0.15	0.16	2.45	1.96
304	Pujol 2002)	20–3-3S	36.4	453	411	0.30	0.15	0.16	2.45	1.96
305	Pujol 2002)	10–2-2.25N	34.9	453	411	0.30	0.15	0.08	2.45	1.96
306	Pujol 2002)	10–2-2.25S	34.9	453	411	0.30	0.15	0.08	2.45	1.96
307	Pujol 2002)	10–1-2.25N	36.5	453	411	0.30	0.15	0.08	2.45	1.96
308	Pujol 2002)	10–1-2.25S	36.5	453	411	0.30	0.15	0.08	2.45	1.96
309	Kono and Watanabe 2000)	D1N30	37.6	461	485	0.25	0.25	0.30	2.43	1.91
310	Kono and Watanabe 2000)	D1N60	37.6	461	485	0.25	0.25	0.60	2.43	1.91
311	Kono and Watanabe 2000)	L1D60	39.2	388	524	0.60	0.60	0.57	1.69	7.81
312	Kono and Watanabe 2000)	L1N60	39.2	388	524	0.60	0.60	0.57	1.69	7.55
313	Kono and Watanabe 2000)	L1N6B	32.2	388	524	0.56	0.56	0.59	1.94	7.55
314	Harries et al. 2006)	L0	24.6	460	438	0.46	0.46	0.25	1.48	0.20
315	Melek and Wallace 2004)	S10MI	36.2	510	481	0.46	0.46	0.07	1.94	0.16
316	Melek and Wallace 2004)	S20MI	36.2	510	481	0.46	0.46	0.14	1.94	0.16
317	Melek and Wallace 2004)	S30MI	36.2	510	481	0.46	0.46	0.21	1.94	0.16
318	Melek and Wallace 2004)	S20HI	35.3	510	481	0.46	0.46	0.14	1.94	0.16
319	Melek and Wallace 2004)	S20HIN	35.3	510	481	0.46	0.46	0.14	1.94	0.16
320	Melek and Wallace 2004)	S30XI	35.3	510	481	0.46	0.46	0.22	1.94	0.16

Acknowledgements

This research was supported by the National Natural Science Foundation of China (52178135).

Authors' contributions
Yanyan Zhu: Software, Data curation, Validation, Writing-Original draft. Jian Zhong: Conceptualization, Methodology, Supervision, Writing-Review and Editing. All authors have read and agreed to the published version of the manuscript.

Funding
This research was funded by the National Natural Science Foundation of China (52178135).

Availability of data and materials
The data and materials in the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests
The authors declare that they have no competing interest.

Received: 28 June 2023 Accepted: 17 August 2023

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