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Original Research Article

Ultimate strengths of FRC rectangular columns subjected to simulated seismic loading: Experimental database and new models

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ABSTRACT

While there are many experimental investigations focusing on seismic behaviour of fibre reinforced concrete (FRC) columns, the studies regarding the accuracies and conservativeness of existing seismic strength models of FRC columns are limited. This paper presents a seismic research database of 322 FRC columns obtained from a comprehensive literature investigation. The characteristic of the database and the effects of main variables on the seismic strengths of FRC columns are analyzed in detail, the accuracies of existing strength models of FRC column are also examined as well. In addition, using the database, considering the effects of fibre and other structural factors on FRC columns, Priestley et al. shear and CFB-FIP moment models are modified respectively. Results show that the two proposed strength models both present better evaluation than other models. On the other hand, a detailed method for assessing the potential failure mode of FRC column subjected to seismic loads is also suggested using the two strength models. The comparative results verify the feasibilities and accuracies of the assessment method in FRC columns.

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1. Introduction

The ultimate strength and potential failure mode of reinforced concrete (RC) members are very important to the design of building structures, for their reasonable analyses and reliable predictions can guide how to prevent sudden and brittle shear failure. With these considerations, high performance concrete (HPC) is being concerned and applied increasingly by structural designers and builders. HPC elements have many benefits for structures majorly including high load capacity, small-cross

section and good durability. Up to now, numerous endeavours have been carried out to improve the understandings of shear resisting and transferring mechanism of RC structural members using HPC subjected various loads. There are also many studies which tried to optimize the design method and damage assessment of HPC structural members. Among these HPCs, fibre reinforced concrete (FRC) does is an important representatives and is being increasingly concerned. The addition of fibre in RC members not only can improve the cracking resistance capacity and flexure strength of members [1], delay the spalling of concrete cover [2,3] and enhance their

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Nomenclatures

ω_1, ω_{1f}	mechanical reinforcement ratio
ρ_L	longitudinal reinforcement ratio
d	overall depth of column, mm
d'	effective depth of column, mm
A_{sl}	area of longitudinal steel, mm ²
P	applied axial load, kN
b	width of columns
f'_c	concrete compressive strength, MPa
ρ_F	fibre volume fraction, %
V_f	shear contribution provided by fibre
V_s	shear component of transverse steel
A_g	gross area of cross section
ν_b	basic shear stress in ASCE-ACI model
f_{vcd}	basic shear stress in JSCE model
ρ_T	area ratio of transverse steel
a/d	shear span ratio of columns
k_f	affecting factors in fibre strength
j	calculative lever depth, mm
c	depth of compression zone, mm
a	calculation height of columns, mm
ρ_{Fp}	polypropylene fibre ratio in concrete
n	axial load ratio of columns
S/d	normalized spacing of shear steel
V_{exp}	experimental shear strength, kN
$V_{sh, cal}$	calculated shear strength, kN
$V_{fl, cal}$	calculated flexure strength, kN
f_{1c}	uniaxial compressive strength of concrete, in MPa
κ_c, κ_{cf}	affecting factor for maximum stress of stress block
f_{yl}	yielding strength of longitudinal steel, in MPa
z	inner lever arm of calculated section, mm
a_{Lt}	area of longitudinal steel in tensile zone, mm ²
N_{max}	ultimate axial compression capacity of columns, kN
N_{min}	ultimate axial tension capacity of columns, kN
x	height of compression zone in section of stress block, mm
a_g	transferring area of longitudinal steel (AIJ code), mm ²
g_1	dimension factor of transferring of longitudinal steel, mm
V_c	shear contribution provided by concrete
A_v	total area of transverse steel with a spacing in transverse
S	spacing of transverse reinforcement, mm
κ	enhancing factor of shear force from fibre
ρ_{Lt}	geometrical longitudinal reinforcement ratio in tension zone
k_u, k_p	affecting factors in concrete shear in Nagasake et al. model
f_{yt}	yielding strength of transverse steel, in MPa
f'_{FRC}	axial compressive strength of fibre concrete
A_e	effective area of section, taken as $0.8A_g$, mm ²
k_{hfc}, k_s	calculation factors of axial compressive strength of FRC

B	factor related to shear contribution in Huang et al. model
A'_e	effective area of cross section in Huang et al. model, mm ²
V_{FRC}	total shear strength of FRC columns proposed in this study, kN
κ_n, κ_{sp}	axial load or a/d affecting factor to moment in Eqs. (13) and (17)
x_f	depth of compression zone of columns, mm

deformation capacity of members [2–8], but also can increase the shear strength of the elements to prevent effectively brittle shear failure.

Bischoff [9] reported that FRC has high tensile resistance capacity involving the initial cracking strength of RC members because they are able to carry tensile forces when they are opened cracks. This can prevent the further development of the cracks and can be transferred into the deformation resisting of members. Besides, the use of fibre can reduce the requirement of transverse reinforcement in FRC members, especially for their seismic design [13]. This is very significant to some important members which usually need a number of reinforcements such as beam-column joints. Therefore, the use of fibre can effectively solve the congestion of rebar in the joints to improve effectively their construction quality [10].

On the basic of the above descriptions, the positive effect of fibre should be considered in the evaluation of ultimate strength and of other properties of FRC members subjected to seismic loads such as ductility and failure and energy dissipation capacity, etc. Most of current design codes such as ACI 318 [11] and Eurocode 8 [12], however, do not take into account the favourable effect of fibre. Moreover, the current design previsions of FRC members are usually empirical and different between various countries in the world [13]. Up to now, there are not internationally accepted calculation models for predicting the ultimate strengths and reliable methods to assess the potential failure mode of FRC members as well. In addition, little thing was known about the accuracy and conservativeness of the existing ultimate strengths models and proposals. This implies that to build seismic research database and to develop a comprehensive method for predicting the failure models of FRC columns are indispensable and significant.

As most important support parts in building structure system in earthquake prone zone, and as a beginning of big seismic database, this paper firstly focuses on the studies of FRC columns. The main objectives of the study have two: (1) to build a seismic research database of FRC columns to study comprehensively and comparatively the existing ultimate strength models of FRC columns; (2) to develop an acceptable judgement method to assess the potential failure modes of FRC columns subjected to seismic loads. It should be noted that this research majorly focuses on the behaviour of FRC columns under simulated seismic loads, i.e. under combined axial and reversed lateral loading. The test data is usually obtained from laboratory investigation which uses small-scale specimen. In summary, this paper

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