STRUCTURAL SAFETY-CATCH OF REINFORCED CONCRETE MEMBER SUBJECTED TO REPEATED EARTHQUAKES

by

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“Dedicated to those who lost their lives in the past earthquakes and wishes for a future where no one in the world loses their life to the earthquakes.”

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LIST OF SYMBOLS

EI	Lateral bending stiffness
EI_1	Initial bending stiffness
EI_2	Secondary bending stiffness
μ_{θ}	Member (rotation) ductility
$\mu_{\theta u}$	Ultimate (Failure) rotation ductility
$\mu_{\theta Y}$	Yield rotation ductility
A	Cross-sectional area
b	Width of the section
c	Thickness of the cover layer
d	Diameter of reinforcement
d_{cr}	Crack displacement
d_y	Yield displacement
E	Modulus of elasticity of the material
E_c	Modulus of elasticity of the concrete
F	Bond force
$f'c$	Uniaxial compressive strength of concrete
f_J	Amount of joint flexibility
fr	Modulus of rupture
$f_{t,s}$	Concrete’s splitting tensile strength
G	Shear modulus of Material
g	Gravity (9.81 m/s^2)
h	Depth of the section

I	Moment of inertia of section
I_g	Gross moment of inertia
K_{cr}	Crack (Initial) stiffness
K_d	Degraded stiffness due to joint flexibility effect
K_{eff}	Effective (Yield) Stiffness
K_m	Total initial elastic stiffness of member (the influence of joint flexibility is included)
K_o	Elastic (Initial) stiffness of member
K_{py}	Post-yield stiffness
l	Distance between two adjacent spring elements
L	Length of member
L_p	Plastic hinge Length of member
m	Lumped mass of member
M	Moment
M_{cr}	Crack moment
M_w	Magnitude of the earthquake acceleration
M_y	Yield moment
P_{cr} / F_{cr}	Crack Force
P_y	Yield Force
R	Distance/ radius of the earthquake from center
r	Post-yield stiffness ratio
s	Slip value
T_n	Natural (elastic vibration) period of SDOF system
υ	Poission's ratio
W	Total weight of member

α	Bi-linear factor (cracking to yield)
α_g	Peak ground acceleration (PGA)
β	Unloading stiffness parameter
βc	Shear transfer coefficient for a closed crack
βt	Shear transfer coefficient for a open crack
δp	Plastic displacement capacity
$\varepsilon_{\circ}$	Strain at maximum stress of concrete
ε_{cu}	Ultimate strain of concrete
σ_{cu}	Maximum/peak compressive strength(stress) of concrete
σ_{tu}	Maximum tensile strength(stress) of concrete
$\tau(s)$	Local bond stress at the bar-concrete interface
ω_n	Natural vibration frequency of SDOF system
Θ_{cr}	Crack rotation
Θ_{jf}	Crack rotation of member due to joint flexibility
Θ_p	Plastic rotation capacity
Θ_u	Ultimate (Failure) rotation
Θ_y	Yield rotation

LIST OF ABBREVIATIONS

APDL	ANSYS Parametric Design Language
BRBFs	Buckling-Restrained Braced Frames
BRBs	Buckling-restrained braces
C1	Single ground motion (GM) case
C2	Double ground motion (GM) case
C3	Triple ground motion (GM) case
CBFs	Concentrically braced frames
CEs	Constraint Equations
CSC1	Test specimen
D.L	Dead load
ED	Seismic energy-Dissipating system
EDP	Engineering Demand Parameter
ESD	European Strong Motion Database
FE	Finite Element
FRP	Fiber Reinforced Polymers
GM	Ground Motion
HYD	High-yield-drift
IDA	Incremental Dynamic Analysis
IM	Intensity measures
IO	Immediate Occupancy level
L.L	Live load
LS	Life safety level

MCE	Maximum considered earthquake
MDOF	Multi Degree Of Freedom system
NTHA	Non-linear inelastic Time History Analysis
OMRF	Ordinary Moment Resisting Frame
OSBs	Ordinary steel bars
PED	Passive energy dissipation devices
PGA	Peak Ground Acceleration
POA	pushover analysis
PSDA	Probabilistic Seismic Demand Analysis
PT	Post-tensioning tendon
q-factor	Seismic force reduction factor
RC	Reinforced Concrete
RC-O	Typical cantilever RC member
RC-SSC	Typical cantilever RC member retrofitted by proposed SSC device
RDs	Residual displacements
SC	Self-centering system
SC-WB	Strong Column-Weak Beam philosophy
SDOF	Single Degree Of Freedom system
SF	Structural Fuse
SFCBs	Steel Fiber Composite Bars
SSC	Structural Safety-Catch
S-SSC	Composite Structure-Structural Safety-Catch device
UBRC	Unbonded Bar Reinforced Concrete

RANGKAP-KESELAMATAN STRUKTUR UNTUK ANGGOTA KONKRIT BERTETULANG TERHADAP GEMPA BUMI BERULANG

ABSTRAK

Matlamat utama dalam kod rekabentuk seismik adalah untuk melindungi nyawa dan keselamatan penghuni bangunan semasa gempa bumi yang teruk. Mencapai matlamat ini memerlukan bahawa risiko keruntuhan struktur adalah diparas yang rendah. Keselamatan keruntuhan disediakan oleh kod seismik semasa cabaran berikutan kemungkinan beban berlebih (gempa bumi mis berulang) dan keadaan system struktur yang tidak sewajarnya yang mustahil untuk meramalkan. Kajian ini mengatasi masalah ini dengan konsep inovatif untuk mencapai sistem struktur baru untuk membaik pulih selepas hasil kekukuhan untuk memohon di dalam anggota rasuk julur biasa bertetulang (RC) yang dianggap sebagai “Single Of sistem Freedom” (SDOF).

Kajian ini dikategorikan kepada tiga langkah utama mengikut tiga objektif kajian. Pertama, kesan pelbagai parameter seperti nisbah kemuluran kekukuhan dan kapasiti putaran plastik kepada sambutan keruntuhan seismik sistem SDOF bersamaan, di bawah gempa bumi berulang, dinilai. Ia telah mendapati bahawa nisbah kekukuhan adalah parameter yang paling berpengaruh yang mempengaruhi tindak balas keruntuhan seismik sistem mulur (sistem SDOF bersamaan dengan kapasiti putaran plastik tinggi) apabila dikenakan semasa gempa bumi berulang.

Kedua, satu mekanisme untuk mencapai sistem struktur baru dengan baikpulih selepas kemuluran kekukuhan telah dibangunkan. Konsep rangkap keselamatan struktur

(SSC) dicadangkan, yang menyediakan potensi menggunakan peranti SSC (sebagai sistem menengah) dalam sistem kemuluran (sebagai sistem utama) untuk pencegahan keruntuhan semasa gempa bumi berulang. Tujuan utama konsep SSC adalah untuk melindungi nyawa dan keselamatan penghuni bangunan semasa gempa bumi yang teruk dengan menyediakan masa tambahan untuk melarikan diri, untuk penghuni. Peranti SSC telah direkabentuk menggunakan mekanikal, di mana lenturan kekakuan menengah disediakan dengan menutup jurang, untuk memasang dalam sistem utama apabila memasuki ke dalam julat tidak boleh berubah. Sistem rendah dan menengah bersama-sama membentuk sistem struktur baru melalui konsep SSC yang dicadangkan yang dikenali sebagai sistem peranti Struktur-SSC (S-SSC).

Ketiga, keluli slotted tiub bulat, sebagai alat SSC (atau sistem menengah), terletak di zon engsel plastik anggota RC julur biasa (sebagai sistem utama) untuk mengelakkan mekanisme runtuh menggunakan sistem S-SSC. Perbandingan dibuat antara anggota RC julur biasa seperti asal anggota RC (RC-O) dan anggota RC julur biasa yang sama dipasang oleh peranti SSC dicadangkan (ahli RC-SSC) itu. Sambutan beban-pesongan anggota RC-SSC mendedahkan pemulihan prestasi selepas hasil, berbanding dengan anggota RC-O, yang mengesahkan kecekapan sistem S-SSC. Tambahan pula, aplikasi dalaman keluli slotted tiub bulat mempunyai kelebihan tambahan melindungi teras anggota itu, dan peningkatan kedua-dua kekukuhan selepas hasil dan kapasiti kemuluran anggota julur RC pada masa yang sama. Engsel plastik juga dipindahkan jauh dari hujung yang tetap (atau dari sendi) bersama-sama panjang anggota untuk di mana jurang keluli dalaman tiub bulat terbentuk. Keputusan ini menunjukkan bahawa kapasiti keruntuhan seismik anggota RC julur biasa telah bertambah baik disebabkan oleh penggunaan peranti SSC dicadangkan.

STRUCTURAL SAFETY-CATCH OF REINFORCED CONCRETE MEMBER SUBJECTED TO REPEATED EARTHQUAKES

ABSTRACT

The primary goal of requirements in seismic design codes is to protect the life and safety of building occupants during severe earthquakes. Meeting this objective requires that the risk of structural collapse be acceptably low. The collapse safety provided by current seismic codes sometimes may be challenging due to possibility of over loading condition (e.g. repeated earthquakes) and improper performance of structural system, which are impossible to predict. The present study overcomes the problem by an innovative concept to achieve a new structural system with quickly recovering post-yield stiffness to apply in a typical cantilever Reinforced Concrete (RC) member that considered as an equivalent Single Degree Of Freedom system (SDOF).

This investigation is categorized into three main steps according to the three objectives of the study. First, the effect of various parameters such as post-yielding stiffness ratio and plastic rotation capacity on the seismic collapse response of the equivalent SDOF systems, under repeated earthquakes, is evaluated. It was found that the post-yielding stiffness ratio is the most influential parameter affecting the seismic collapse response of the ductile systems (the equivalent SDOF systems with high plastic rotation capacity) when subjected to repeated earthquakes.

Second, a mechanism for achieving the new structural system with quickly recovering lateral post-yield stiffness is developed. The Structural Safety-Catch (SSC) concept is proposed, which provides the potential of utilizing a SSC device (as a