ANALYTICAL AND EXPERIMENTAL BEHAVIOR OF THE SEISMIC FILLED ACCORDION METALLIC DAMPERS USING HYPERFOAM FILLERS

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***Abstract**: The idea of the energy dissipation in buckling of thin-walled tubes under axial cyclic loading lead to development of an accordion metallic damper (AMD) as a valid seismic energy absorption damper for installing in chevron braced frames. Of cousre AMD's have many advantages against available metallic dampers, but need to improve and developing for behavior stability and increasing low cycle fatigue strength.*

In this paper, for the purpose of improvement and modifying the buckling behavior of AMD's, filled accordion metallic dampers(FAMD) are introduced and It's parameters have been defined, then analytical Finite element model of AMD and FAMD's have been developed and a series of parametric analytical studies have lunched on FAMD's for the determination of the approximate preliminary specifications of different polymers for potential use. After specifying the preliminary material properties, a series of AMD's and FAMD's filled by polyurethane foam were subjected to dynamic tension and compression actuator. Based on the results obtained, using suitable fillers inside AMD's is an efficient method for the purpose of preventing destructive buckling such as diamond mode which in turn improves low cycle fatigue strength of AMD's. Separation between fillers foam and accordion thin-walled tubes because of stress concentration and the generation of contact force is an important parameter of failure in FAMD's, of course this separation occur less for full fill FAMD's.

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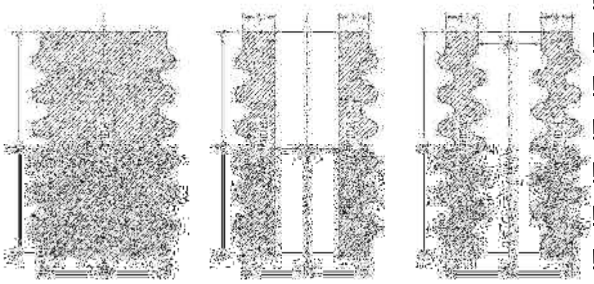

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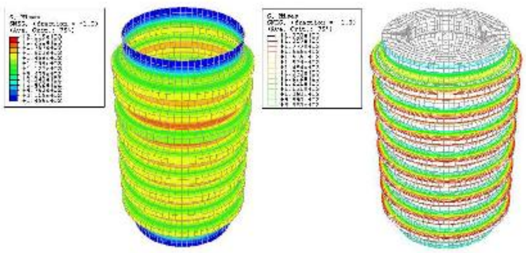

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!B[?=3H62! 73P0! >! v PD! 13] . / 2! 0*! 39#)%T)! @WA! p3G)*! 7%SHTF !'103 / ! u3Z!72! (J*(?=!QR)!1%<)!\/@ / *!1562(J!1234. / *! (NW=*! ' f>7 !5H6E(0! f %‰!72!B)%C273DE! + 03)!7*58!&39#$%$!#D!@ / *!&*#)%]F!&* !72!L*7>2!#)%]_?9!L5F! ž $3 : !&7%<=!&>(?)! u3Z!BX)38!&7*•J73F !&3-.)*!>2!72!B I 6*(a!V?H ; ! f %R•!7%SHTF!\/5HHDB=!YT<A!*7!3-.)* !Q / 3H=! 23I F*! 3F! xHN0! >2! 2*5 I A! cB)%C273DE! + 03)! 7*58! &39#)%T) !72! 39#)%T)! QR)! 7%SHTF! \/@ / *! 15a! 12*2! L%J7E! &...%4)! • %8 !15a!#. : 3 / ! >! B•*(‰! 7%SH=! V65F! ! #D! f 3RA*! K0! >2! 0*! 13] . / 2 !15a!12*2! L3P)! k3?CM8! K TD!3F!3- [0! V6*! \/22(JB=!1234. / *! @ / * !&3-GHN0!>!1562(J!QR)! 13] . / 2! &391(?J! Y : *2! 72! ¤~£! Y [a!72 !YR.=!3- [0! V6*!3F! @=>3^=(b! &3-_?b!0*!1234. / *!3F!#)%T)!&3-.)*!>2 !k7%RF! k3P63=0E! &*(F! &7*•J73F! &39%]$*! \/22(JB=! { [<=!>!15a !{-=! &39#R : 3a! L*%.F! #D! @ / *! 1562(J! B•*(‰! &%<HF! BN[A>(b !!\/2%T)!V??I A!*7!LE!&>7!(F! k3)3 / %)! g)3D(0!(?Ž*A!>!(J*(?=

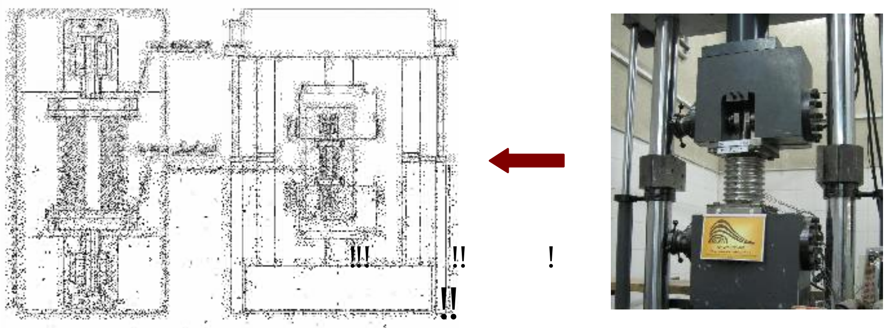
!3F! 15HHD(b! 123=! L*%H I F! L3A7>*! BNb! (6•b! ¢3 I I)*! p%0! \/@ / *! 15a !V6*!72!\/@ / *!#.0(J!7*(Z!1234. / *!27%=!1M?=E!w67MA! • >7!0*!1234. / * !(J*(?=!BN : *2!– I / !cd% I / !&03 / 123=E!7%SHTF!(=*!&*5.F*!72! • >7 !!!\/22(JB=!@ / , F!5H /

!36! >! 73])0! #)%J(9! 0*! d% I / !&03WD3b! 7%SHTF! @ / , F! 5H / ! k3?NT, !3F! 39#)%T)! BN : *2! – I / ! #=*2*! 72! \/2(?JB=! k7%e! B$3T.•*! #W?Nb !p%0! u% : !BJ5HXW ; !@N I F!\/22(JB=!BC*20!BF(; !L%. / *!0*!1234. / * !1234. / *! BWD%b*! 0*! B)%C273DE! 17*58!' p%0! + (.P=!YR0! 72! 2Œ%0!> !!!\/@ / *!1562( ])

!L*M?=! #H?=0! 72! M?)! Be3 : ! k3 I$3 I =! @ / *! p0Œ! f3•! (9! #F !Q?D(A!0*!@$3•!V6*!72!\/2(6•b!k7%e!M?)!17*58!#F!p%0!BJ5HXW ; !>! B•*(‰! 15HHD! @n / ! V?H_T9! >! 3-?)2>M0*! c#?$>*! 2*%=! 0*! Be3 : !(b! 7%SHTF! \/22(JB=! &(?J! Q$3Z! #)%T)! Y : *2! #D! 2%P?=! 1234. / * !VN?A*!BNb! g H8!0*!*MG=!&3-X$3Z!c i N.n=!&3-h?A!3F!39#)%T)!L2%T) !!!\/@ / *!15a!#. : 3 / !>!B•*(‰!L%N4A!>

! g h / ! 22(JB=! (b! >! 15a! #.n67! #)%T)! Y : *2! 15a! #. : 3 / ! 1M?=E !>!12%T)! • >*(A! L>(?F! #F! B03€*! 1M?=E! c15a! #)%T)! 27*>! 3 I 6(/ ! Q$3Z !(S)! 27%=! Q$3Z! \/5)3=B=! BZ3F! #)%T)! Y : *2! 1M?=E! 03?)! 27%=! L*M?= !\/22(JB=! { [<=!7%SH=!V65F!15a!B•*(‰!&5HF([?b!>!1(?J!#N? / %F !YT, ! @, (/ ! 22(JB=! @n / ! „6(/ ! 73?WF! 7%D•=! 1M?=E! #D! 3G)E! 0* !Q$3Z! 0*! 5 I F! \/5a3FB=! 7*27% : (F! Be3 : ! @?T9*! 0*! @$3<H6*! 72! *(8* !*7! (S)! 27%=! B.n / ! 3F! p%0! >! 15a! @n / ! (S)! 27%=! 1M?=E! c&(?J !!!\/22(JB=!5?$%A

!c&7>EYT, ! &*(F!03?)!27%=!#?$>*!w63Z2!72!1M?=E! { G• ! v 6*M0*!@N I F !(b! Y=3D! 7% I F! 73P0! @<A! B)%C273DE! + 03)! 7*58! #$%$! &39! #W?Nb !!!\/5)2(JB=



"">T"&*25*"mn*";"Š>) '>0QU"1> ' *!" [- .%(€$X"Š>$\/ \C"s ' "_eG

+T>?) '>0QU" [> / R " V"F@"=@>MR , !"@F20" [F! "]F>\/" [>T2?6!"Š>$\/ \C"s•" I ; - C

g)3•(0	!!(.T?N?=!QW•!(F!(`•*5•!#H=*2!¤#H=*2!(9!72!Y<? / !2*5 I A£								!! f 3H] ? / !z%)	!!&7*•J73F
	n=9	n=8	n=6	n=5	!!n=4	n=3	n=2	n=1		
!!MA(9!"¬‡	•~¤ ∀ £	!!•"¤•£	!! | ~¤•£	!! | "¤•£	!!‡~¤•£	!!‡"¤•£	!!~¤ | £	!! | ¤ | £	$A_n Sin(! t)$	*SL-1*
!!MA(9!"¬~	•~¤ ∀ £	!!•"¤•£	!! | ~¤•£	!! | "¤•£	!!‡~¤•£	!!‡"¤•£	!!~¤ | £	!! | ¤ | £	$A_n Sin(! t)$	*SL-2*

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""+T>?) '>0QU" [>/R " V" • '>R*"&Y!F!"sK

=-G"(X"(]!($0"+?R„$"]";"+3€G"($$–V" [>T@20"sKOD !72! cB$3 : %A! B)%C273DE! (J*(?=! #)%T)! #F! j %F(=! BN[a! (??yA! 2%= !B)%C273DE! v)3TD! z%)! 0*! &7%<=! Y[a! (??yA! K ; %D! &39#H=*2 !(??yA! &39#H=*2! 72! B$>! 12%F! 39#W?Nb! 72! Y[a! (??yA! MD(TA! L>5F !3F! 1*(T9! B)%C273DE! v)3TD! c(.T?.)3 / ! |¬~! 2>5•! 72! (.J7MF! BN[a !B)3?=! &39#W?Nb! 72! B / 3T$*! v)3TD! V?H_T9! >! Y[a! (??yA! MD(TA !72! 3=*! U@ / *! 1562(J! (J*(?=! @W[a! Q8%=! 3.63-)! #D! 12%F! 1*(T9 !MD(TA! u(n=! 2%=! cp%0! 3F! 15a! (b! (J*(?=! &39#)%T)! 0*! p*5[_?9 !1593P=!2360!&3-N[a!(??yA!#H=*2!72!B.•!39#W?Nb!V?F!Y[a!(??yA !L>5F! B)%C273DE! v)3TD! Y=3a! c39#)%T)! BN[a! (??yA! 2%=! >! 562(]) !3A! &7%<=! Y[a! (??yA! &39#H=*2!72!39#W?Nb! V?F! Y[a! (??yA! MD(TA !•!2>5•! &7%<=! Y[a! (??yA! &39#H=*2! 72! U@ / *! 12%F! (.T?.)3 / ! • !39#)%T)! V6*! 72! B / 3T$*! v)3TD! 3F! B)%C273DE! v)3TD(ÆE3F! >! (.T?.)3 / !12*2! Ÿ7! (J*(?=! B].n?WJ! #?•3)! L3T9! 72! 3.63-)! >! 1562(J! 1*(T9 ST-!c!ST-2!c!ST-1!&39#)%T)!72!3e%R : !15HHD(b!123=!7% - •!U@ / * !(.T?.)3 / ! • !#H=*2!3A! (J*(?=!BP)3TD!73.07!d , e*!@-8!72!ST-6!>!5 !&Œ3F! &39#H=*2! 72! B. • ! 3-N[a! (??yA! MD(TA! 0*! &(?J%N8! 7%SHTF ! v)3TD! u(n=! 2%=! 0>(F! 0*! &(?J%N8! V?H_T9! >! BN[a! (??yA !!!U@ / *!12%F!(Žœ=! , =3D!(.T?.)3 / ! • !#H=*2!3A!B / 3T$*

!0*!Ba3)!3=%T, !15a!(b!&39(J*(?=!72!B / 3T$*! v)3TD!2%=!0>(F!@N, !Y=3, !U@ / *!123.0*!®34A*!Y?$2!>2!#F!(=*!V6*!#D!5a3FB=! v HA!MD(TA !>!@ : 3 / !5H6E(0!72!#D!@ / *!B<$3R=!>!B / 5H9!&3-R^)!2%8>! f>* !15HHD!(b!p%0! v 6*58!p>2!Y=3, !>!5.0*B=!®34A*!39#$%$!B92!Y[a !72!>!2360! BN[a! (??yA! #H=*2! 72! B)%C273DE! 17*58! BN : *2! – I / ! 0* !17*58! >! p%0! V?F! +(.P=! YR0! 72! +3[I e*! 23G6*! LE! #G?.) !BC3-H.F!p%0! BJ5HXW ; !L*M?=!#D!5 / 7B=!(SHF!U5a3FB=!B)%C273DE !17*58! p%0! 3F! 73J03 / ! >! Q / 3H=! BWD%b*! 0*! 1234. / *! >! 12%X)! B03D !!U22(]?=!#?e%A!BAE! k3I$3 I =!72!Y - I=!V6*! „07!7%SHTF!B)%C273DE !!

!&39#H=*2! 3F! B / %H? / ! &%]$*! ! k7%RF! 15a! B•*(‰! &3-67*•J73F !U5a3FB=!15)%a!7*([A!&3-N[? / !72!L3[=(??yA! f(.HD!3F!1*(T9!(?y.= !15a! 127>E! ¤"£f>58! 72! &7*•J73F! &%]$*! V6*! #F! j %F(=! k3?CM8 !173Ta! Y=3a! k3P63=0E! p3G)*! „=38! #=3)(F! M?)! ¤~£! f>58! 72! U@ / * !k3?CM8! (63 / ! >! v 63=0E! (9! 72! 15a! f3T, *! &7*•J73F! &%]$*! c#)%T) !!!U@ / *!15a!127>E! K ? [4A!#F! v 63=0E!(9

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""=-G"(X"(]!($0" [>T"&*25*"Š>) '>0QU"&0>*(%"sN I ; -C

!! g H8 !!15HHD(b	!&%]$* BJ5a(b	!!&7*•J73F	#)%T)	!! v 63=0E
L3A7>*!BNb!p%0	F	SL-1	!!S1	ST-1
L3A7>*!BNb!p%0	S.F	SL-1	S2	!!ST-2
L3A7>*!BNb!p%0	S.F	SL-2	S2	ST-3
L3A7>*!BNb!p%0	S.F	SL-1	S3	ST-4
L3A7>*!BNb!p%0	S.F	SL-1	S3	ST-5
L3A7>*!BNb!p%0	S.F	SL-1	S3	!!ST-6
L3A7>*!BNb!p%0	S.F	SL-1	S4	ST-7
L3A7>*!BNb!p%0	S.F	SL-1	S5	ST-8
L3A7>*!BNb!p%0	S.F	SL-2	S5	ST-9
B$3 : %A!#)%T)		SL-1	S	ST-10

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Š>) '>0QU"1>'*!"sPOJ

!72! 15a! #.0(J! (S)! 72! #=3)(F! 3F! wF3 I =! 15a! B•*(‰! &3-67*•J73F !U@ / *!1562(J! f3T, *!39#)%T)!#F!5a!–6(PA!#D!B.?4?D!3F!¤~£! f>58 !&7*•J73F! &%]$*! >! 12%F! u(n=! k7%RF! #.0(J! k7%e! k3P63=0E !#=*2*! 72! U22(J! @W[a! 73 ; 2! #)%T)! #D! @ / *! #.036! #=*2*! &%<HF !!U22(JB=!–6(PA!#.0(J!k7%e!&3-.WA!0*!#Ne3•!k*593P=!>!x63.)

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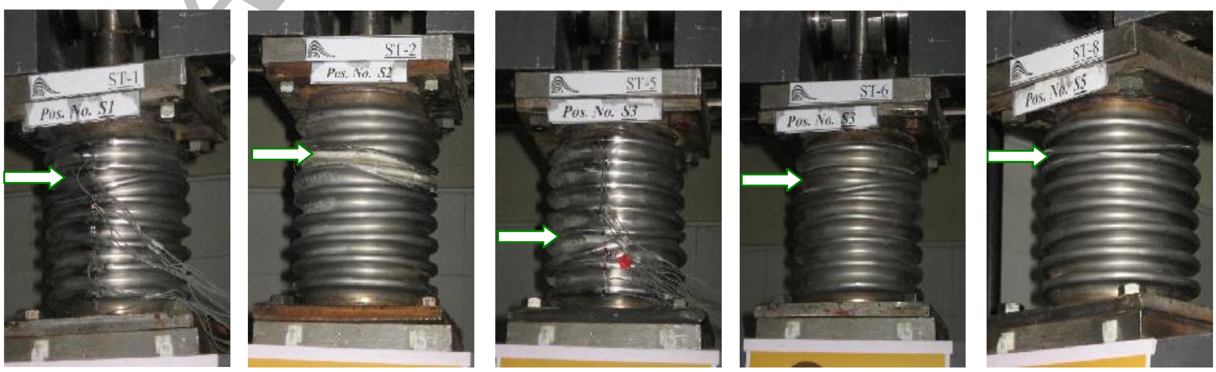

!!$ST-1# !!$ST-2# !!$ST-5# !!$ST-6# !!$ST-8#

""W(R5$R*>, "J"@; -~"F@"&.0!@"t"12S">%"=-G"(X" u 3R„0" [>T"&*25*"F@"+ , >56!"—*>5Z"@20"Q; (%"sP_eG

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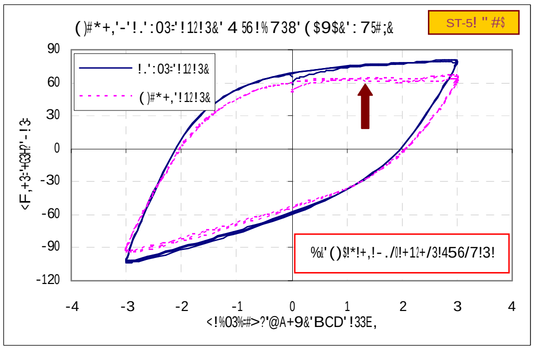
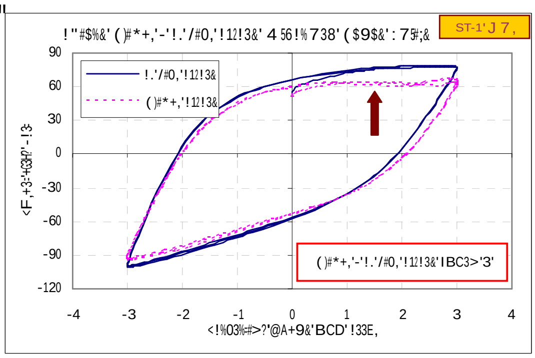


wxt



wu6!t

"" (R5$R*> , "J"+3€G"($$–V"&.0!@"F@"(]!($0"_~! -%"=- . . Z(X"=@>0"7 -G"&S>...!">%"+6>~2V"(]!($0"+) *>5Z"F>RSF"zš : !"sK_eG
!!ST-5"8 " V"gw x t"" **ST-1**"8 " V"g"w u 6!t

!!

!#)%T)! B : (F! 72! ƒ3H. ,*! YF3Z! B / 5H9! &3-R^)! 23G6*! ( ])3?F! (=*! V6* !>! B92! Y [a! 5H6E(0! V? • ! 72! B$3 : %A! B)%C273DE! + 03)! 7*58! &39 !72! 3-)E! @ : 3 / ! 5H6E(0! L2%F! B. / 2! #F! #8%A! 3F! #D! @ / *! LE! @ : 3 / !!U5 / 7BT)! (SHF!5?!F!w?^<A!V6* !!

"">T&*25*"8 " V"Q!"=- G"v! („R , !" [>T&n~>G"sP I ; - C

"8 MZ ""7 - G(X	"+R„ , ""Œ$R , >!	"@! - 9V ""_€$,	"" [2?6! +] - G(X	&*25*	""—'>0QU
!!'	*ton*/*cm*			'	'
{$3/	"2¬°±	3´	(b!p3TA	!!S1	ST-1
{$3/	µ¬´	32	(b!#T?)	S2	!!ST-2
BH0! ž ^)!@NIF!@WA! i Z%A			(b!#T?)	S2	ST-3
u%?I=	´¬µ	"µ	(b!#T?)	S3	ST-4
{$3/	""¬°	3¶	(b!#T?)	S3	ST-5
{$3/	"2¬3	3°	(b!#T?)	S3	!!ST-6
{$3/	´¬"¶	"´	(b!#T?)	S4	ST-7
u%?I=	±¬´3	32	(b!#T?)	S5	ST-8
BH0! ž ^)!@NIF!@WA! i Z%A			(b!#T?)	S5	ST-9
!!'	!!µ¬"°	33	B$3 : %A	S	ST-10

!!

"""=- G"(X" [>T( ]!($0" ˆ 'Q(R " $T" [F>RSF" [>/$. L. 0"sKOy !15a! (b! (J*(?=!&39#)%T)!#F! j %F(=! g 60(.W?9!&3-?H<H=!B / 7(F!3F ! ž :3a! L*%HIF! g 60(.W?9! BH<H=! (60! – I / !#D!22(JB=!#S • , = !15a!@WA!#)%T)!#F!#.WF! ·~!3A!(`D*5•!BP6*M0*!(J*(?=!&'()*!u•8 !B$3 : %A! (J*(?=!#F!@XW)!&7%<=!Y [a! (??yA! i N.n=!&39#H=*2!72 !L3W [6! 3X6(^A! >! Q / 3H=! „60%A! 0*! v 6*M0*! V6*! U@ / *! #.a*2 !0*!&(?J%N8!BHITF!B)%C273DE!&39#W?Nb!V?F!&7%<=!&3-N [a(??yA !@?0(o!U22(JB=!Ba3)!B)%C273DE!&39#W?Nb!72!3-N [a(??yA!MD(TA !73S.)*!27%=!#_)3H ; !73P0!72!1r6%F!>! v PD!72!M?)! (J*(?=!K?. / , b

!p%0!3F!15a! (b!#)%T)!5H ; !72!B / 3T$*! v)3TD!2%=!0>(F!¤•£!Y [a!72 !U@ / *!15a!12*2!L3P)! (.T?.)3 / ! •!2>5•!72!BN [a! (??yA!#H=*2!72 ! v)3TD!2%=!36!>!Y [a! (??yA!MD(TA!3F!B)%C273DE! v)3TD!2%=!0>(F !3-HA! >! 27*5)! g 60(.W?9! BH<H=! Y [a! (F! &23?HF! k*(?Ž'A! B / 3T$* ! g 60(.W?9!BH<H=!&73P0!@TWZ!72!{D!#H=*2!3F!BA3)3 / %)! k7%RF !72!B$3 : !%A!B)%C273DE! (J*(?=!BP)3TD!73.07!d , e*!U22(JB=!7*565b ! g 60(.W?9! BH<H=!&>7!p%0!3F!15a! (b ST-5!>!ST-1!&39#)%T) !15a!12*2! L3P)!¤>£!Y [a!72! (.T?.)3 / ! •!#H=*2!&*(F!39#)%T)!V6* !@WA! 0*! 15a! m*(n. / *! &39 ž :3a! B : (F! ¤•£! f>58! 72! U@ / * !U@ / *! 15a! 127>E! 39#)%T)! L5a! (b! B4?D! @?I€>! 1*(T-F! 39#)%T) !0*! #.0(J! k7%e! BH?, ! B / 703F! 3F! >! @WA! p3G)*! 0*! 5 IF! #)34 / '.= !0(I F! ST-8! >! ST-4! &39#)%T)! #D! 5a! ž nP=! #)%]H6*! C39#)%T) !&3-R^)!3F!>!@?^?D!BF!3-)E!72!15a!#.n67!p%0!>!15P)! (b!Q / 3H= !Q / 3H=!5?$%A! ™ : !# [H6*! Y?$5F! (=*!V6*!#D!U@ / *!12%F!1*(T9!&2360 !@W63FB=!73D!V6*!>!12%X)!2%8%=!39#)%T)!Y : *5F!p%0!w67MA!&*(F !!U@ / *!BI?X‰!c5aB=!p3G)*!B. / 2!k7%RF !Y=3, ! K6!2% : ! LE!72! ž ^)!2%8>!>!15a!#.n67!p%0!L2%F!V]T93) !2% : !B F%nF! (=*!V6*!>!12%F!39#)%T)!V6*!72! v HA!MD(TA!23G6*! u(n= !U@ / *!12*2!L3P)!39#)%T)!V6*! ™ / %A!15a!YT<A!Y [? / !2*5IA!72!*7 !3F!¤(b!p3TA£!ST-1!&39#)%T)!15a!YT<A!&3-N [? / !2*5IA! ¯?•!0* !@?I€>! 0*! Y [? / ! |~! 3F! ¤(b! #T?)£! ST-5! V?H_T9! >! Y [? / ! | } !!U5Ha3FB=!7*27% : (F!39#)%T)! (63 / !#F!@XW)!&(.X / 3H= !@XW)!*7!&(.P?F!Y [? / !2*5IA!ST-1! (b!p3TA!#)%T)!L3?=!V6*!72!> !# [H6*! #F! {N, ! 3F! (=*! V6*! #D! @ / *! 12%T)! YT<A! ST-5! #)%T)! #F !12%F! (.TD! (b!p3TA!#)%T)!72!B)%C273DE!17*58!0*!p%0! v 6*58! f 3T. •* ! v 93D! ( ]62!#8%A!YF3Z!#. [ ]!U@ / *!#?8%A!YF3Z!5.0*B=!®34A*! (A(62!> !p%0!3F!15a! (b!&39#)%T)!B : (F!&*(F!&7%<=! K?. / Œ*!B.n / !L*M?= !B.n / !2>7B=! 73S.)*! # [?$3 • ! 72! 5a3FB=! B$3 : %A! #)%T)! #F! @XW) !!U5F36! v 6*M0*!LE!Y : *5F!p%0!L5a!#03€*!3F! (J*(?=! K?. / Œ*

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!#F! #8%A! 3F! #D! @/*! #.036! v 6*MO*! B/%W<=! 5•! 3A! c5a3FB=! M?)
!*7!17*58!>!p%0! v HD75)*! k*(Ž!1234./*!27%=!p%0!&3-?.n/!2>5•
!{.W?/!&'()*!u•8!L*M?=!V?H_T9!>!K?./,b!@?0(o! v 6*MO*!72
!p%0!2%8>!#l/*%F!(J*(?=!cB].n?WJ!0*!5lF!U592B=!L3P)!BF%nF
!@n/!73.07!2%:!0*!&7%<=!BJ2(P0!2360!&39#H=*2!72!LE!Y:*2
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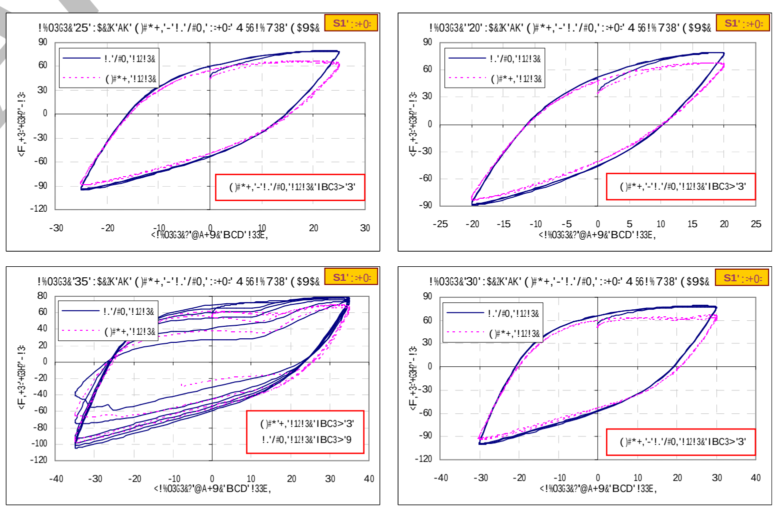

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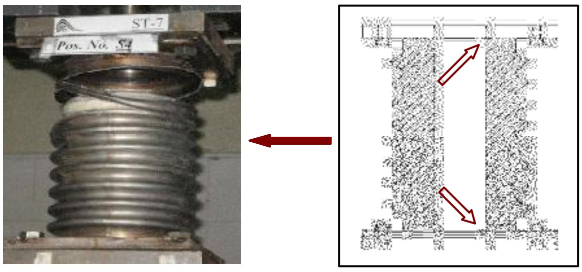

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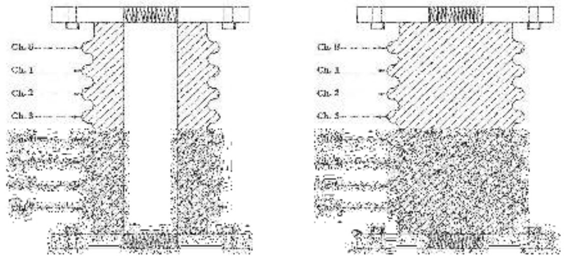

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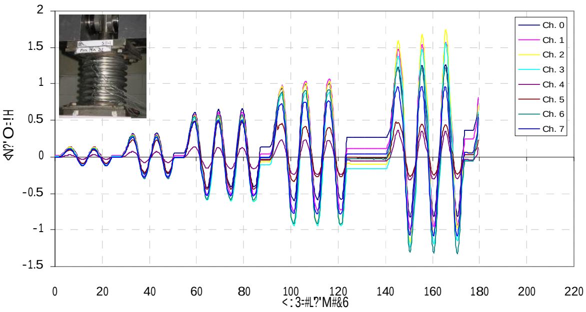

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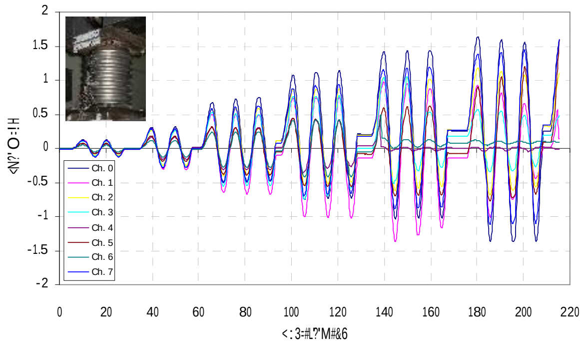

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!7*58!&39!#$%$!2(F73D!c f3T85?/!c7%b!BH?W•!cV?W<=,-!c¸P)*2!1•†
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