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(SMA)

Archive of SID

Olsson .

[] Abrate

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Sun .

[] Chen

Birman .

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[] Mei

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$$\begin{matrix} \psi_y & \psi_x \\ \cdot & x \ y \end{matrix}$$

[] Schetky [] Wu [] Rogers

$$(A_{16}=A_{26}=D_{16}=D_{26}=B_{ij}=0)$$

[] Kim Roh

$$N_y^i \ N_x^i$$

[] Sun

[] Birman

Birman

$$D_{11}\psi_{xxx}+D_{66}\psi_{xyy}+(D_{12}+D_{66})\psi_{yxy}-k_{sh}A_{55}\psi_x$$

Roh

$$-k_{sh}A_{55}w_x = I\psi_x \quad (-)$$

$$(D_{12}+D_{66})\psi_{xxy}+D_{66}\psi_{yxx}+D_{22}\psi_{yyx}-k_{sh}A_{44}\psi_y$$

$$-k_{sh}A_{44}w_y = I\psi_y \quad (-)$$

[]

$$k_{sh}A_{55}\psi_{x,x}+(k_{sh}A_{55}+N_x^i)w_{xx}+k_{sh}A_{44}\psi_{y,y}$$

$$+(k_{sh}A_{44}+N_y^i)w_{yy}+q=\rho\ddot{w} \quad (-)$$

k_{sh}

[] Mindlin

$\pi^2/12$

$y \ x$

$$(A_{ij}, B_{ij}, D_{ij}) = \int_{-h/2}^{h/2} Q_{ij}^k(1, z, z^2) dz \quad (i, j = 1-6)$$

$$(A_{ij}) = \int_{-h/2}^{h/2} Q_{ij}^k dz \quad (i, j = 4, 5)$$

$$(\rho, I) = \int_{-h/2}^{h/2} \rho_0(1, z^2) dz$$

[] Pagano Whitney

()

ρ

ρ_0

$$u = u^0(x, y, t) + z\psi_x(x, y, t)$$

$$v = v^0(x, y, t) + z\psi_y(x, y, t)$$

$$w = w^0(x, y, t)$$

()

$$Q_{ij} \ (i, j = 4, 5)$$

[]

$$w^0 \ v^0 \ u^0$$

h

$a \ x \ b$

$z \ y \ x$

$$\alpha_i^c (i=1,t) \quad []$$

$$k_c \quad k_s \quad \Delta T$$

$$w = \psi_{x,x} = 0 \quad ; \quad \text{at } x = 0, a$$

$$w = \psi_{y,y} = 0 \quad ; \quad \text{at } y = 0, b$$

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$$\begin{Bmatrix} N \\ M \end{Bmatrix} = \begin{bmatrix} A & B \\ B & A \end{bmatrix} \begin{Bmatrix} \varepsilon^0 \\ \kappa \end{Bmatrix} + \begin{Bmatrix} N_r \\ M_r \end{Bmatrix} - \begin{Bmatrix} N^T \\ M^T \end{Bmatrix}$$

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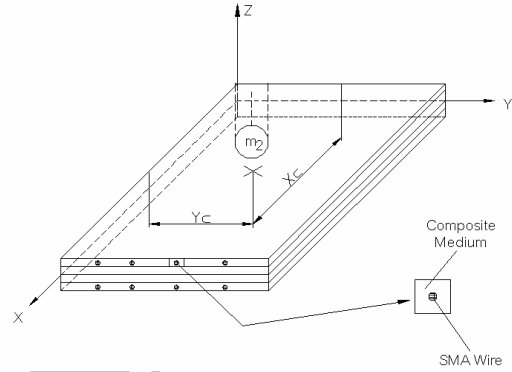
$$\begin{bmatrix} M & N \\ D & B & A \end{bmatrix}$$

()

$$M_r \quad N_r$$

$$M^T \quad N^T$$

$$\kappa \quad \varepsilon^0$$



$$B = M_r = M^T = 0$$

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$$\begin{Bmatrix} N_x \\ N_y \\ N_{xy} \end{Bmatrix} = \begin{bmatrix} A_{11} & A_{12} & 0 \\ A_{12} & A_{22} & 0 \\ 0 & 0 & A_{66} \end{bmatrix} \begin{Bmatrix} u_{,x} \\ v_{,y} \\ u_{,y} + v_{,x} \end{Bmatrix} + \begin{Bmatrix} N_{rx} - N_x^T \\ N_{ry} - N_y^T \\ 0 \end{Bmatrix}$$

$$\begin{Bmatrix} M_x \\ M_y \\ M_{xy} \end{Bmatrix} = \begin{bmatrix} D_{11} & D_{12} & 0 \\ D_{12} & D_{22} & 0 \\ 0 & 0 & D_{66} \end{bmatrix} \begin{Bmatrix} -w_{,xx} \\ -w_{,yy} \\ -2w_{,xy} \end{Bmatrix}$$

()

$$\begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{Bmatrix} = \begin{bmatrix} Q_{11} & Q_{12} & 0 \\ Q_{12} & Q_{22} & 0 \\ 0 & 0 & Q_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12} \end{Bmatrix}$$

$$+ \begin{Bmatrix} \sigma_r \\ 0 \\ 0 \end{Bmatrix} k_s - \begin{bmatrix} \bar{Q}_{11} & \bar{Q}_{12} & 0 \\ \bar{Q}_{12} & \bar{Q}_{22} & 0 \\ 0 & 0 & \bar{Q}_{66} \end{bmatrix} \begin{Bmatrix} \alpha_1^c \\ \alpha_t^c \\ 0 \end{Bmatrix} k_c \Delta T$$

()

$$\begin{matrix} \tau_{12} & \sigma_2 & \sigma_1 \\ \varepsilon_2 & \varepsilon_1 & \gamma_{12} \end{matrix}$$

$$\bar{Q}_{ij} \quad Q_{ij}$$

$$\sigma_r$$

$$k_1 = F_m^{1/3} k_c^{2/3}$$

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$$k_1 = k_2$$

$$F_m$$

:

[]

$$k_c \left(- \right)$$

$$m_2 \ddot{z}_2 + F = 0$$

$$m_1 \ddot{z}_1 + k_{bs} z_2 + k_m z_2^3 - F = 0$$

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$$k_c = \frac{4}{3} \frac{R_2^{1/2}}{\frac{1-v_2^2}{E_2} + \frac{1}{E_1}}$$

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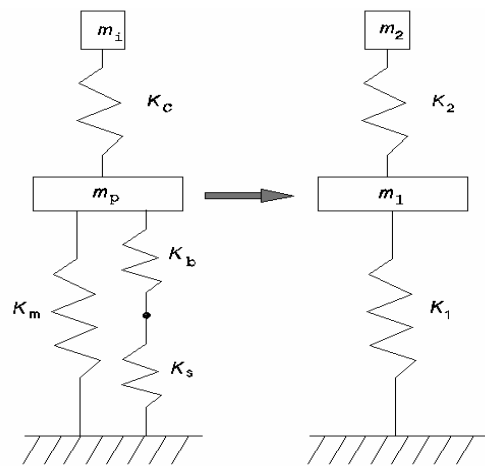
E_2 E_1

v_2

R_2

()

F



(: -

:

$$m_1 \ddot{z}_1 = -k_1 z_1 - k_2 (z_1 - z_2)$$

[]

(

$$m_2 \ddot{z}_2 = -k_2 (z_2 - z_1)$$

()

m_p

m_1 ()

m_i

m_2

z_2 z_1

MATLAB

ODE 45

k_s

k_{bs}

k_b

k_m

F

k_m

()

()

()

()

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[]

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$$F = k_1 \alpha$$

()

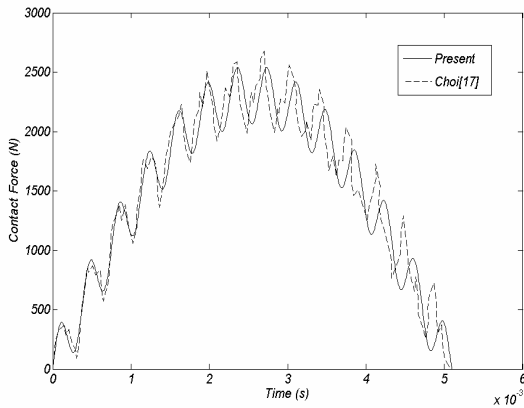
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$$\ddot{W}_{mn}(t) + \omega_{mn}^2 W_{mn}(t) = \frac{Q_{mn}(t)}{\rho h} \quad ()$$

$$\omega_{mn}^2 = \frac{L_{13} K_A + L_{23} K_B + L_{33}}{\rho h} \quad ()$$

$$W_{mn}(t) \quad ()$$

$$\begin{bmatrix} w \\ \psi_y \\ \psi_x \end{bmatrix} = \begin{bmatrix} W_{mn}(t) \\ B_{mn}(t) \\ A_{mn}(t) \end{bmatrix} \quad ()$$



$$\begin{bmatrix} L_{11} & L_{12} & L_{13} \\ L_{12} & L_{22} & L_{23} \\ L_{13} & L_{23} & L_{33} \end{bmatrix} \begin{bmatrix} A_{mn}(t) \\ B_{mn}(t) \\ W_{mn}(t) \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ Q_{mn}(t) - \rho h \ddot{W}_{mn}(t) \end{bmatrix} \quad ()$$

$$\psi_x(x, y, t) = \sum_{m,n=1}^{\infty} A_{mn}(t) \cos\left(\frac{m\pi}{a}\right)x \sin\left(\frac{n\pi}{b}\right)y \quad ()$$

$$\psi_y(x, y, t) = \sum_{m,n=1}^{\infty} B_{mn}(t) \sin\left(\frac{m\pi}{a}\right)x \cos\left(\frac{n\pi}{b}\right)y \quad ()$$

$$w(x, y, t) = \sum_{m,n=1}^{\infty} W_{mn}(t) \sin\left(\frac{m\pi}{a}\right)x \sin\left(\frac{n\pi}{b}\right)y \quad ()$$

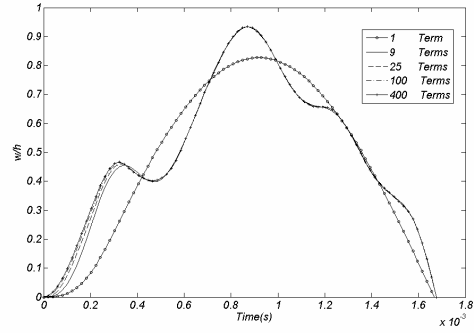
$$q(x, y, t) = \sum_m \sum_n Q_{mn}(t) \sin\left(\frac{m\pi}{a}\right)x \sin\left(\frac{n\pi}{b}\right)y \quad ()$$

$$\begin{bmatrix} L_{11} & L_{12} & L_{13} \\ L_{12} & L_{22} & L_{23} \\ L_{13} & L_{23} & L_{33} \end{bmatrix} \begin{bmatrix} A_{mn}(t) \\ B_{mn}(t) \\ W_{mn}(t) \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ Q_{mn}(t) - \rho h \ddot{W}_{mn}(t) \end{bmatrix} \quad ()$$

$$\begin{aligned} L_{11} &= D_{11} \left(\frac{m\pi}{a}\right)^2 + D_{66} \left(\frac{n\pi}{b}\right)^2 + k_{sh} A_{55} \\ L_{12} = L_{21} &= (D_{12} + D_{66}) \left(\frac{m\pi}{a}\right) \left(\frac{n\pi}{b}\right) \\ L_{13} = L_{31} &= k_{sh} A_{55} \left(\frac{m\pi}{a}\right) \\ L_{22} &= D_{66} \left(\frac{m\pi}{a}\right)^2 + D_{22} \left(\frac{n\pi}{b}\right)^2 + k_{sh} A_{44} \\ L_{23} = L_{32} &= k_{sh} A_{44} \left(\frac{n\pi}{b}\right) \\ L_{33} &= (k_{sh} A_{55} + N_x^i) \left(\frac{m\pi}{a}\right)^2 + (k_{sh} A_{44} + N_y^i) \left(\frac{n\pi}{b}\right)^2 \end{aligned} \quad ()$$

$$\begin{aligned} A_{mn}(t) &= K_A W_{mn}(t) & B_{mn}(t) &= K_B W_{mn}(t) \\ K_A &= \frac{L_{12} L_{23} - L_{13} L_{22}}{L_{11} L_{22} - L_{12}^2} & K_B &= \frac{L_{12} L_{13} - L_{11} L_{23}}{L_{11} L_{22} - L_{12}^2} \end{aligned} \quad ()$$

()



[]

0.20 0.12

x

(-)

) w/h

)

1.55 (

0.75 (

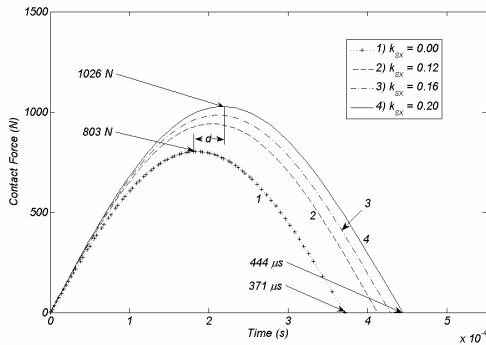
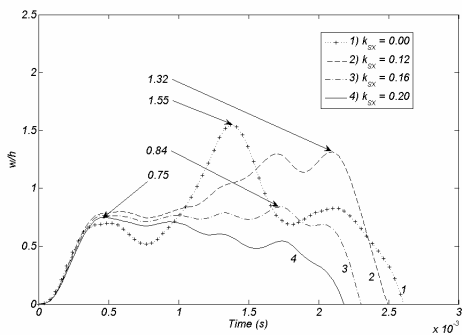
52

0.20

[]

:

200 mm	=
[0/90/0/90/0] _s	
0.269 mm	
(-)	
E ₁₁ = 23.062 GPa ; E ₂₂ = E ₃₃ = 10.789 GPa	
G ₁₃ = G ₁₂ = 11.92 GPa ; G ₂₃ = 4.68 GPa	
ν ₁₂ = ν ₁₃ = ν ₂₃ = 0.344	
ρ = 1796 kg/m ³	
) Ni-Ti	
(
E = 70 GPa	
G = 26.32 GPa	
ν = 0.33	
ρ = 6500 kg/m ³	
σ _r = 220 MPa at ΔT = 39 °C	
E = 207 GPa	
ν = 0.30	
ρ = 7800 kg/m ³	
Tip diameter = 0.0127 m	
Weight = 1.50 kg	
Impactor velocity = 2.00 m/s	

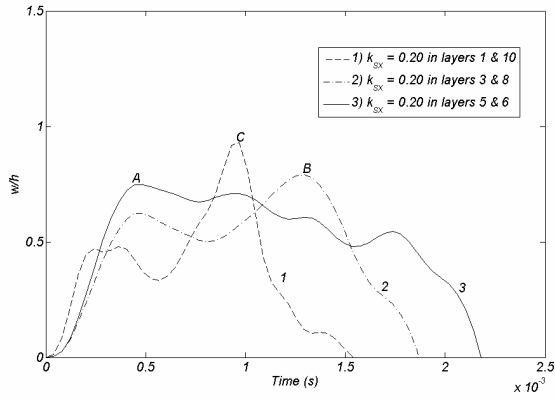


(w/h (: :

0.20

(-)

X



N (MCF)

1026 N

803

0.20

28

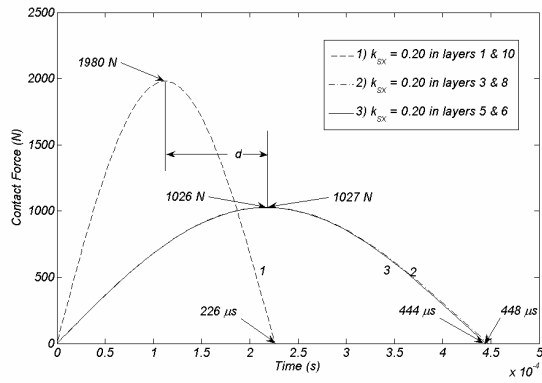
(d)

(MCFT)

444 μs

371 μs

(CT)



CT

MCFT

(w/h (: :)

(-)

()

[]

(1026 N)

MCFT MCF

((-))

CT

1980 N 1026 N

448 μs

(d)

226 μs

((-))

MCF

()
(CT MCFT)

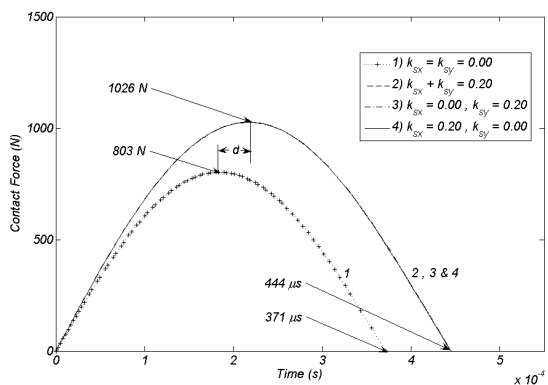
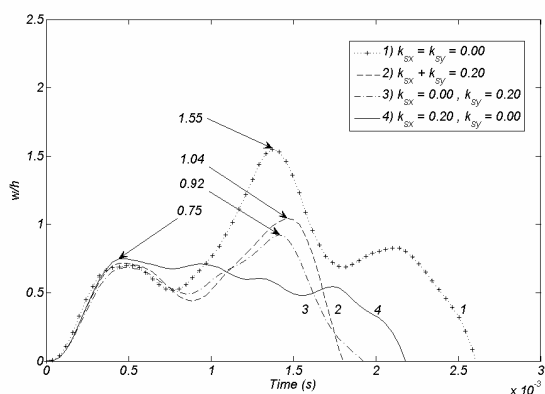
)C

B

A

(((-)

(((-))



(w/h (:

y x

y
x

: ()

(-)

(x)

()

w/h

)

52 (

41 ()

(-) (-) (-)

(-)

(-)

(())

0.20

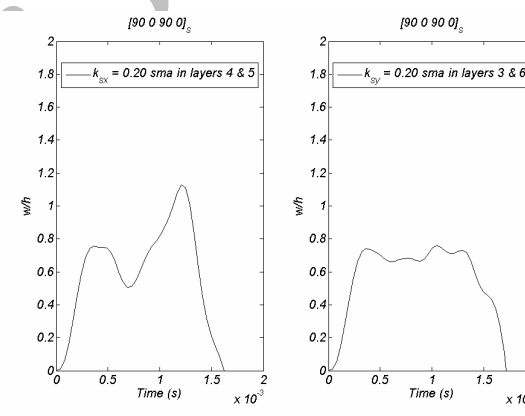
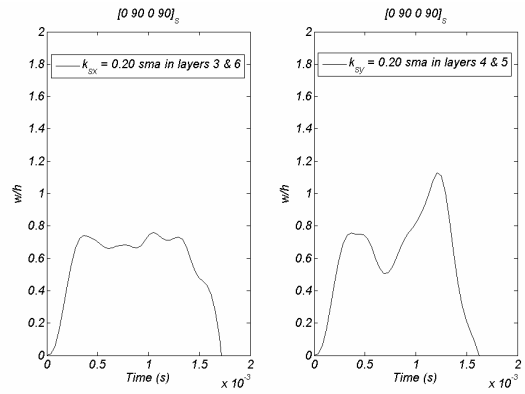
y x
[90/0/90/0]_s [0/90/0/90]_s

()

(-)

x

x



(-)

y

w/h :

[0, 90, 0, 90, 0]_s

.90° 0°

[0, s

θ = 0, 15, 30, 45, 60, 75, 90°

θ, 0, 0, 0]

x

0.20

(-)

(-)

(-)

(-)

()

A₂₆ A₁₆

(-)

(-)

(-)

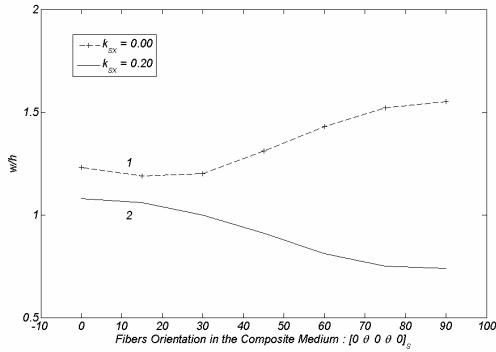
(-)

(-)

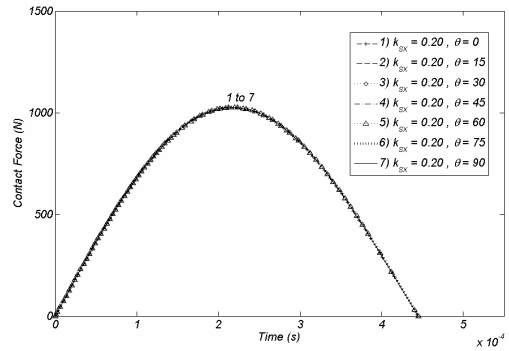
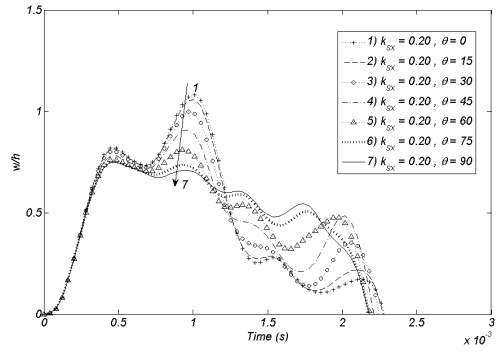
(-)

w/h

() 1.08 0° w/h
 [] 0.75 90° w/h
 31 90° 0°
 w/h
 (-)



. w/h



w/h (: : (

Archive

()
 ()
 ()
 (30° 0°) θ

(8)
 (90° 30°)

$\theta = 0^\circ$

(31)
 ()
 x

w/h

MCFT MCF

CT

w/h

90° 0°

y x

: w^0, v^0, u^0

z y x

: Ψ_y, Ψ_x

y x

: N_y^i, N_x^i

x

y

: k_{sh}

: q

: I

MCF

: Q_{ij}

CT MCFT

: a, b

: h

: ΔT

: k_c, k_s

w/h

: M, N

: B, D A

: M_r, N_r

: M^T, N^T

: m_2, m_1

: z_2, z_1

: k_{bs}

: k_b

w/h

: k_s

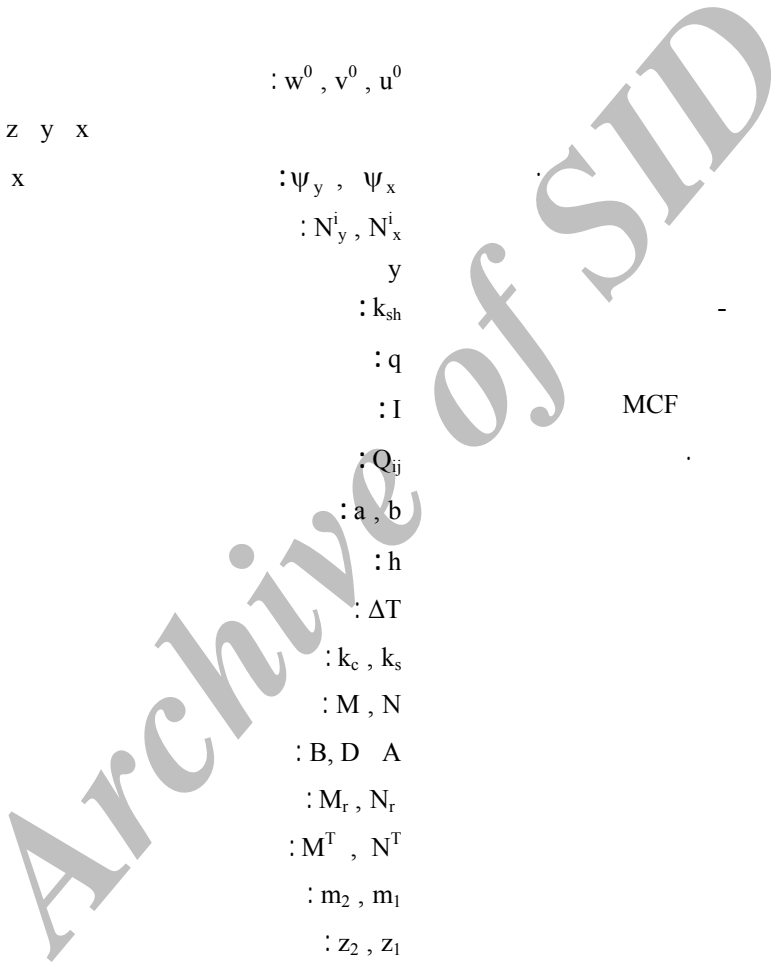
: k_m

: F

: $k_1 = k_2$

: k_c

: F_m



	$\gamma_{12} \quad \varepsilon_2 \quad \varepsilon_1$: R_2
		: E_2, E_1
	: σ_r	: $W_{mn}(t), B_{mn}(t), A_{mn}(t)$
t	: $\alpha_i^c (i=1,t)$: Q_{mn}
l	: κ, \mathcal{E}^0	: $F(t)$
	: v_2	: G
	: ω_{mn}	: MCF
		: MCFT
		: CT
	: 0	
	: i	
	: $[]$: ρ_0
	: $[\bar{ }]$: ρ
		: $\tau_{12} \quad \sigma_2 \quad \sigma_1$
y	x	: ,

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|--------------------------------------|------------------------------------------------|
| 1 - Shape Memory | 2 - Low Velocity Impact |
| 3 - Contact Force | 4 - First Order Shear Deformation Plate Theory |
| 5 - Fourier Series Method | 6 - spring-Mass Model |
| 7 - Tensile Recovery Stress | 8 - Classical Plate Theory |
| 9 - Global Impact | 10 - Cross Ply- Balanced Symmetric Laminates |
| 11 - Choi's Linearized Contact Model | 12 - Hertzian's Contact Theory |
| 13 - Maximum Contact Force | 14 - Maximum Contact Force Time |
| 15 - Contact Time | 16 - Impulse |
| 17 - Stiffness | 18 - Localized Phenomenon |