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## ***Effect of Functionally Graded Core on Dynamic Response of Sandwich Panel subjected to Transverse Low-velocity Impact***

M.H. Shakib, S.M.R. Khalili, K. Malekzadeh

### ***ABSTRACT***

In this paper, the problem of low-velocity transverse impact on a sandwich panel with functionally graded core has been considered. The interaction between the impactor and the panel is modeled with the help of a system having two-degrees-of-freedom consisting of springs-masses. In order to determine the contact force history, a numerical procedure is employed based on improved higher-order sandwich plate theory. Shear deformation theory is used for the face sheets while three-dimensional elasticity theory is used for the core. For the first time effect of consideration of in-plane shear stress and normal stress in the core is considered. Displacement components in the core are assumed to vary with a polynomial function with unknown coefficients. Results indicate that use of the FG core can reduce deflections and increase maximum of contact forces.

**KEYWORDS :** Sandwich panels, Functionally graded core, Low-velocity impact, High-order theory

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(HSAPT<sup>1</sup>)

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(IHSAPT<sup>2</sup>)

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h

b a

[ ]

h<sub>b</sub> h<sub>c</sub> h<sub>t</sub>

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$$\begin{aligned}
 & \{ \dots \} \\
 & [K] \{X_0^*\} = \{0\} \\
 & \{u_0^t, \psi_x^t, v_0^t, \psi_y^t, w_0^t, u_0^b, \psi_x^b, v_0^b, \psi_y^b, w_0^b, u_0^c, u_1, v_0, v_1, w_0\} \\
 & [K] \quad [M]
 \end{aligned}$$

$$\delta \int_{t_1}^{t_2} (U + V - T) dt = 0 \quad (1)$$

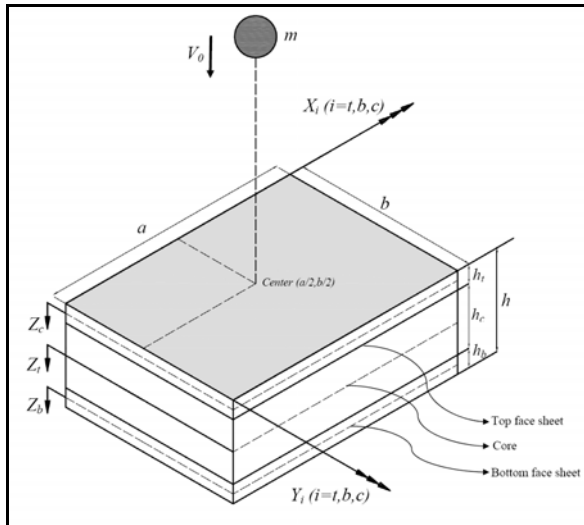
$$\begin{aligned}
 & \delta \\
 & (t_1 - t_2) \\
 & [ ]
 \end{aligned}$$

$$\begin{aligned}
 \delta U = & \int_{V_i} (\sigma_{xx}^t \delta \varepsilon_{xx}^t + \sigma_{yy}^t \delta \varepsilon_{yy}^t + \tau_{xy}^t \delta \gamma_{xy}^t + \tau_{xz}^t \delta \gamma_{xz}^t + \tau_{yz}^t \delta \gamma_{yz}^t) dv \\
 & + \int_{V_b} (\sigma_{xx}^b \delta \varepsilon_{xx}^b + \sigma_{yy}^b \delta \varepsilon_{yy}^b + \tau_{xy}^b \delta \gamma_{xy}^b + \tau_{xz}^b \delta \gamma_{xz}^b + \tau_{yz}^b \delta \gamma_{yz}^b) dv \\
 & + \int_{V_c} (\sigma_{zz}^c \delta \varepsilon_{zz}^c + \sigma_{yy}^c \delta \varepsilon_{yy}^c + \sigma_{xx}^c \delta \varepsilon_{xx}^c + \tau_{xy}^c \delta \gamma_{xy}^c + \tau_{xz}^c \delta \gamma_{xz}^c + \tau_{yz}^c \delta \gamma_{yz}^c) dv
 \end{aligned} \quad (2)$$

$$\varepsilon_{ii}(i=x, y) \quad \sigma_{ii}(i=x, y) \quad (3)$$

$$\varepsilon_{zz}^c \quad \sigma_{zz}^c$$

$$\begin{aligned}
 & \sigma_{yy}^c \delta \varepsilon_{yy}^c \quad \sigma_{xx}^c \delta \varepsilon_{xx}^c \\
 & \tau_{xy}^c \delta \gamma_{xy}^c
 \end{aligned} \quad (4)$$



(5)

$$\begin{aligned}
 u_c(x, y, z_c, t) &= u_0(x, y, t) + z_c u_1(x, y, t) + z_c^2 u_2(x, y, t) + z_c^3 u_3(x, y, t) \\
 v_c(x, y, z_c, t) &= v_0(x, y, t) + z_c v_1(x, y, t) + z_c^2 v_2(x, y, t) + z_c^3 v_3(x, y, t) \\
 w_c(x, y, z_c, t) &= w_0(x, y, t) + z_c w_1(x, y, t) + z_c^2 w_2(x, y, t) \quad (6) \\
 & v_k(k=0, 1, 2, 3) \quad u_k \\
 & w_k(k=0, 1, 2)
 \end{aligned}$$

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$$M_{eff}^P \quad m_1$$

$$M_{eff}^P$$

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$$K_c^* \quad K_g \quad [ ]$$

[ ]

$$\Delta_2 \quad \Delta_1$$

[ ] [ ]

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$$K_c^* = K_c^n F_{max}^{\frac{n-1}{n}} \quad ( )$$

$$F_{max} \quad K_c$$

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$$\frac{F_{max}^2}{2K_g} + \frac{F_{max}^{1+\frac{1}{n}}}{(n+1)K_c^{\frac{1}{n}}} = \frac{1}{2}mv_0^2 \quad ( )$$

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$$E_c = 380 \text{ GPa}, \rho_c = 3800 \text{ Kg/m}^3$$

$$K_g = M_{tot} \omega_{11}^2 \quad ( )$$

$\omega_{11}$

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$$E_m = 70 \text{ GPa}, \rho_m = 2707 \text{ Kg/m}^3$$

$M_{tot}$

/

$$\Delta_2 \quad \Delta_1$$

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(a/h)

$$F(t) = K_c^* (\Delta_1 - \Delta_2) \quad ( )$$

[ ]

(n)

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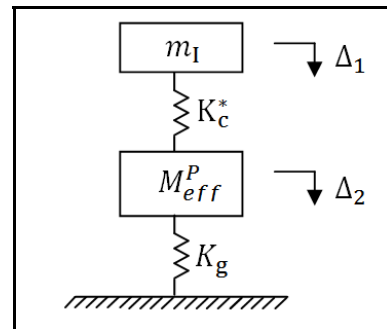
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$$\rho_0 = \text{Kg/m}^3 \quad E_0 = \text{GPa}$$

$$\bar{\omega} = \frac{\omega a^2}{h} \sqrt{\rho_0 / E_0} \quad ( )$$

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(n=1,10)



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$(a/b = a/h = / \quad h_c/h = / \quad )$

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$E_{11}(GPa)$		/
$E_{22}(GPa)$		/
$E_{33}(GPa)$	/	/
$G_{12}(GPa)$	/	/
$G_{13}(GPa)$	/	/
$G_{23}(GPa)$	/	/
$n_{12}$	/	/
$n_{13}$	/	/
$n_{23}$	/	/
$r(Kg/m^3)$		
$h_c(mm)$		/
Ply Thickness (mm)	/	
$a(mm)$	/	/
$b(mm)$	/	/

$a/h=1 \cdot$			
$n$		[ ]	
		/	/
		/	/
		/	/
		/	/
		/	/
$a/h=1 \cdot \cdot$			
$n$		[ ]	
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		/	/

(SOFD<sup>3</sup>)

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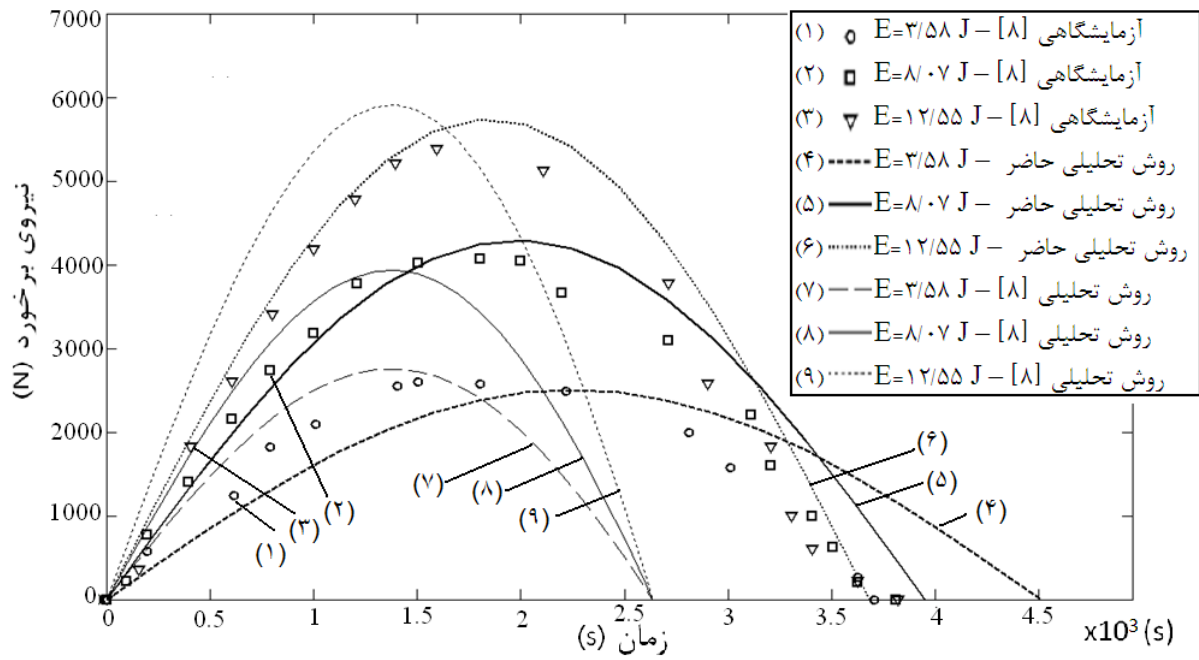
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[0 90 0]



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	/	/	/

b= mm      L= mm  
 $h_c =$  mm  
 $h_f =$  / mm  
 / GPa

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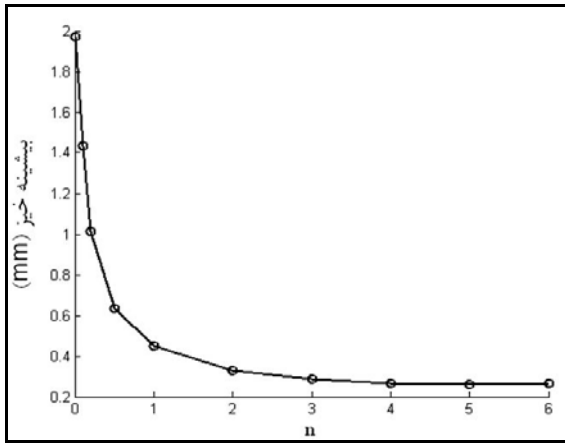
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(a)

(n=)  
n>

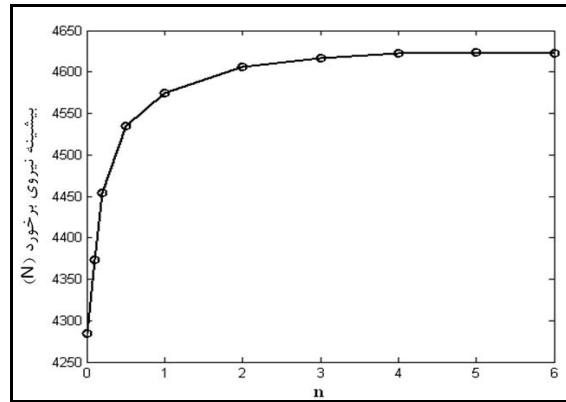
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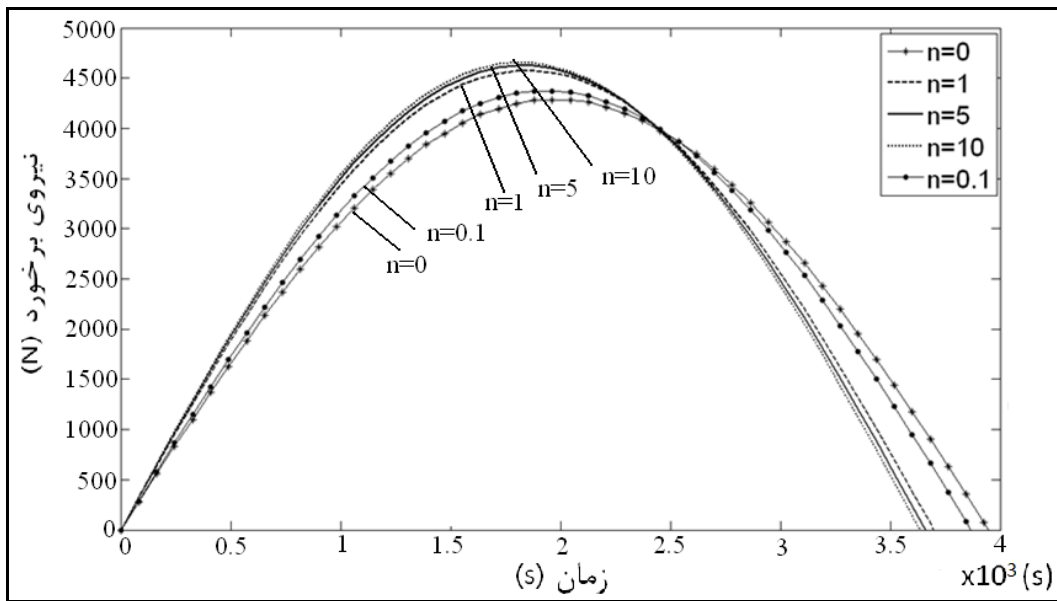
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(b)



(c)

- Anderson, T.A.; "An investigation of SDOF models for large mass impact on sandwich composites", *Journal of Composites Part B*, vol. 36(2), p.p. 135–142, 2005. [ ]
- Etemadi E., Afaghi Khatibi A., Takaffoli M., "3D finite element simulation of sandwich panels with a functionally graded core subjected to low velocity impact". *Journal of Composite Structures*, vol. 89(1), p.p. 28-34, 2009. [ ]
- Frostig, Y.; Thomsen, O. T.; "High-order free vibration of sandwich panels with a flexible core", *International Journal of Solids and Structures*, vol. 41, p.p. 1697–1724, 2004. [ ]
- Malekzadeh, K.; Khalili, M.R.; Mittal R.K.; "Local and global damped vibration of plates with a viscoelastic soft flexible core: an improved high-order approach", *Journal of Sandwich Structure and Materials*, vol. 7, p.p. 431-456, 2005. [ ]
- Khalili, M.R.; Malekzadeh, K.; Mittal, R.K.; "Effect of physical and geometrical parameters on transverse low-velocity impact response of sandwich panels with a transversely flexible core", *Journal of Composite Structures*, vol. 77, p.p. 430-443, 2007 [ ]
- Choi, I.H.; Lim, C.H.; "Low-velocity impact analysis of composite laminates using linearized contact law", *Journal of Composite Structure*, vol. 66, p.p. 125–32, 2004. [ ]
- Suresh, S.; Mortensen, A.; *Fundamentals of Functionally Graded Materials*, IOM Communications Limited, London, United Kingdom, 1998. [ ]
- Koizumi, M.; "FGM activities in Japan" *Composites Part B*, vol. 28, p.p. 1–4, 1997. [ ]
- Li, Q.; Iu, V.P.; Kou, K.P.; "Three-dimensional vibration analysis of functionally graded material sandwich plates", *Journal of Sound and Vibration*, vol. 311, p.p.498-515, 2008. [ ]
- Chi, S.H.; Chung, Y.L.; "Mechanical behavior of functionally graded material plates under transverse load— Part I: Analysis", *International Journal of Solids and Structures*, vol. 43, p.p. 3657–3674, 2006. [ ]
- Prakash, T.; Singha, M.K.; Ganapathi, M.; "Thermal postbuckling analysis of FGM skew plates", *Engineering Structures*, vol. 30, p.p. 22-32, 2008. [ ]
- Delale, F.; Erdogan, F.; "The crack problem for a nonhomogeneous plane", *ASME Journal of Applied Mechanics*, vol. 50, p.p. 609–614, 1983. [ ]
- Apetre, N.A.; Sankar, B.V.; Ambur, D.R.; "Low-velocity impact response of sandwich beams with functionally graded core", *Journal of Solids and Structures*, vol. 43, p.p. 2479-2496, 2006. [ ]

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<sup>1</sup> Higher-order Sandwich Plate Theory

<sup>2</sup> Improved Higher-order Sandwich Plate Theory

<sup>3</sup> Single Of Freedom Degree

