# A computational static parametric study of a polystyrene sandwiched composite structural system

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**Abstract**

Now-a-days sandwich composite materials play a significant role for energy efficient constructions. The reinforced concrete-polystyrene sandwich material prove to be an excellent composite in recent times. As static loads play an inevitable role in causing damage in structure, computational investigations of the proposed sandwich composite structures seems to be a primary necessity. However, the computational study of structural behaviour of the same is quite sparse in India. This proposed paper involves the computational investigation on the structural behaviour of the proposed composite panel on subjection of static loads. Finite Element Analysis are conducted by using ANSYS Workbench 15 simulations to compute the static parameters of the structural system under specific boundary conditions. In the second part of the proposed paper a sensitivity analysis of the nodes of a sandwich composite system is done on the basis of static structural property namely transverse deflection to find out the set of Sensitive Nodes (SN).Response of those nodes would guide and certainly assure about any damage occurred in the structure.

**Keywords:** Polystyrene, Sandwich Composite, Static loads, Transverse deflection, Sensitivity, Finite Element Analysis, Sensitive nodes

## 1 Introduction

Sandwich composite panels seems to be better approach in building construction in recent times. The reinforced concrete-polystyrene sandwich panel could be a good option to use as a shear wall as well as slab. It plays a significant role in thermal and acoustic impedance. It has several structural advantages too like reducing self-weight, better resistance to dynamic loading because of higher stiffness to mass ratio, It also consumes less construction time and less construction cost.

The first part of proposed paper involves computational study on static loading under different boundary condition. The static behaviour like transverse deflection, strain energy and stress generated in the sandwich composite panel due to static loading is

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computed and compared. Occurrence of damage is very common to take place because the structure is generally exposed to the ambient nature. Thus the response of static parameters are evaluated for different damage situation like changing in the location of damage or varying the type of damage which guides to discover the effective damage later on.

There are few literatures available both numerical and computational study on sensitivity analysis using dynamic parameter. But dynamic sensitivity analysis is moreover complicated due to requirement of sophisticated instruments and influence of several types of uncertainties including measurements and model assumed etc. On the contrary static sensitivity analysis procedure is simple and it has less complication in collection of measurements. And also damage only consists of reduction in stiffness in static analysis, so a very simple parameter like transverse displacement may be used as a parameter to evaluate the sensitive nodes. The second part consists of evaluating sensitivity of different nodes on the face sheet due to different type of damage and location. The response of static transverse deflection is computed at each node for every set of damage and then a set of sensitive nodes (SN) is chosen which may consist of one or more. All the member nodes of the set should be selected in such a way so that any type of damage at any location can be detected only depending on the change of their parameter response. Any difference in response at any node would confirm that there is damage in the structure.

# 2 Model

The proposed structural insulated composite panel was modeled in Finite Element Analysis based ANSYS Workbench 15 by assembly. Hence modelling details of different parts are given below

a) Core: The polyethylene core having dimension of 1m by 1m with 60 mm thickness has been modelled in “SOLID” platform. The core was assigned with the material properties of conventional polyethylene given in Table-1
b) Face sheets: The top and bottom concrete face sheets are of the same dimension and same material properties, which has been modeled by “SOLID” extrusion. Each of the face sheets are of 1m by 1m with 35 mm thickness. The face-sheet was assigned with the material properties of concrete which is given below in the Table-1.
c) Reinforcement bars: The reinforcement bars having circular cross-section of dia 3mm and length of 1 m were modeled as “LINE” element. Both axial and flexural behaviour is considered for this numerical model. The bars were placed at both orthogonal direction of the panel. The reinforcement bar was assigned with the conventional material property of gray cast iron as given in Table-1.
d) Shear connectors: The shear connector was assumed as axial member in this model and hence has been modeled as “LINE” element. The cross-section

of bars is circular with dia of 3mm. and placed along the transverse direction at 100 mm c/c distance both ways. It was assigned with the same material property of the reinforcement bars.

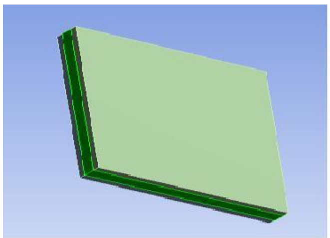


Fig : Core and face sheet

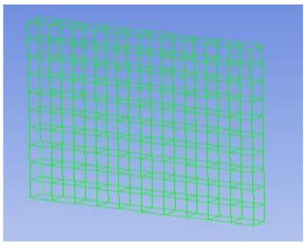


Fig : Reinfocement bars and shear connectors

**Table1: Material properties of different parts of model**

| Property | Concrete | Gray cast iron | Polystyrene |
|---|---|---|---|
| Density(kg/m$^3$) | 2300 | 7200 | 950 |
| Young's Modulus (Pa) | 3E+10 | 1.1E+11 | 1.1E+09 |
| Poisson's ratio | 0.18 | 0.28 | 0.42 |
| Bulk Modulus (Pa) | 1.5625E+10 | 8.3333E+10 | 2.2917E+09 |
| Shear Modulus (Pa) | 1.2712E+10 | 4.2969E+10 | 3.8732E+08 |
| Tensile Ultimate strength (Pa) | 5E+06 | 2.4E+08 | 3.3E+07 |
| Compressive Ultimate strength (Pa) | 4.1E+07 | 8.2E+08 | 0 |

The "CONNECTIONS" between different parts are discussed below

a) "Face to face rough" contact between core and face-sheets was applied.
b) Applying "bonded" contact between reinforcement bars and face-sheets.
c) Applying "bonded" contact between shear connectors and core
d) Applying "bonded" contact between shear connectors and face sheets.
e) Shear connectors and reinforcement bars are connected through rigid joint at every junction of wire mesh.

# 3 Results and Discussions

## 3.1 Static Characteristics:

A uniform pressure of magnitude 1kPa is subjected normal to the top face sheet of the above mentioned composite model of thickness 130 mm. and three static parameters namely transverse deformation, strain energy and total equivalent strain are evaluated for different boundary condition. Four different boundary conditions are a) Fixed at one face, b) Fixed at two adjacent faces, c) Fixed at four corners, d) Simply supported at four corners.

The deformed shape of the panel and also the magnitude of the static characteristics varies depending on the boundary condition as shown below in fig 5-7.

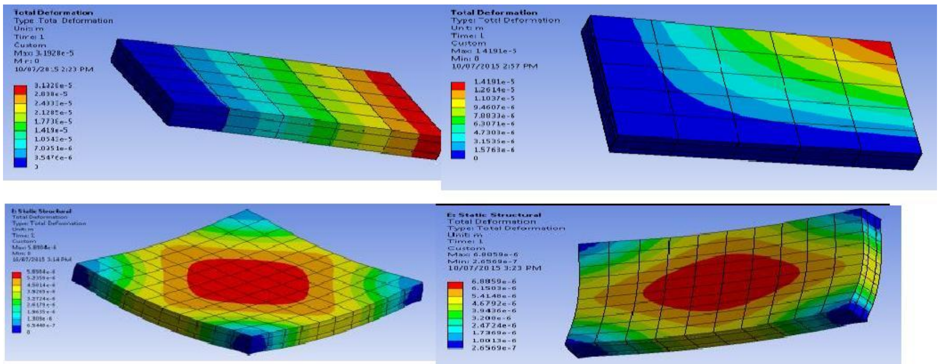


Fig 5: Transverse deformation of the panel under different boundary conditions (a-d)

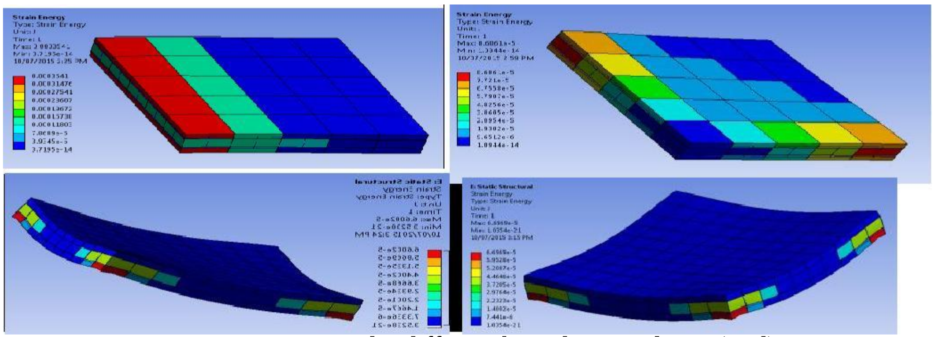


Fig 6: strain energy under different boundary condition (a,-d)

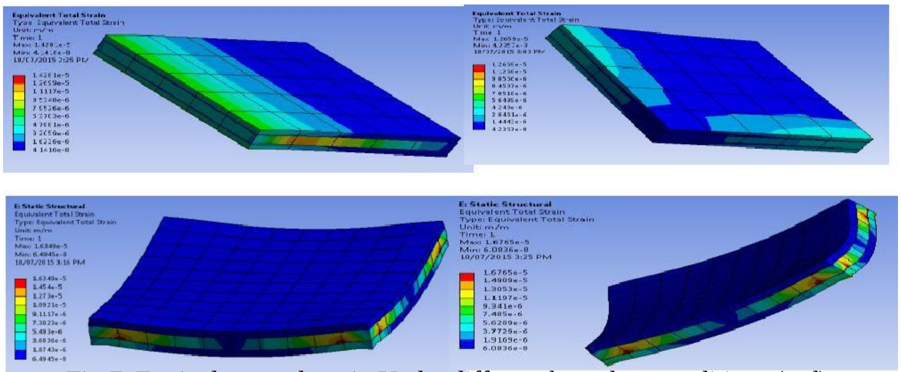


Fig 7: Equivalent total strain Under different boundary conditions (a-d)

Deformed shape of panel for each boundary condition is shown below and the max transverse deformation, max strain energy and max total equivalent strain are collected and is represented in the Table 2.

Table 2: Static characteristics of the panel under different boundary condition

| Boundary condition | Max transverse deformation (m) | Strain energy (max) (J) | Equivalent total strain (max) |
|---|---|---|---|
| B.C (a) | 3.1921E-05 | 3.541E-04 | 1.4281E-05 |
| B.C (b) | 1.4191E-05 | 8.6861E-05 | 1.2659E-05 |
| B.C (c) | 5.8904E-06 | 6.6002E-05 | 1.6349E-05 |
| B.C (d) | 6.8859E-06 | 6.6969E-05 | 1.6765E-05 |

Max strain energy generated under B.C (a) is almost four times higher than that of B.C (b) because the max moment generated for the first case is almost two times of that for the second case and the strain energy is proportional to the square of the moment. Under the second case of boundary condition unlikely strain energy generated at the junction of the two adjacent fixed faces is zero in spite of having max moment. This can be explainable with the concept of curvature and the dependence of strain energy on it. As this part of the model is fixed both wise the curvature of that part of the panel turns into zero which converts the strain energy as zero. It is also observed that the max strain energy was generated at both other end part of the fixed surfaces which also because of increase in curvature and having a higher amount of fixed moment but not maximum. For the both case of boundary condition of (c) and (d) the max strain energy is generated at the support end. And for the first case it is slightly higher just because of more fixity. The total equivalent strain considers elastic, plastic and creep of materials at a time. Thus though the maximum transverse deformation is higher for B.C (b) than that of B.C (c) ,the maximum total equivalent strain is higher in case of B.C (c) as more part of the panel is subjected to large deformation under transverse loading condition. The total equivalent strain at the face sheets is very negligible compared to the core as its stiffness is comparatively higher. Significantly the thickness of core is reduced and the planar dimension is increased more with respect to others due to its higher poison's ratio. Now a circular damage is induced at the centre of the panel in different material. Change of response with parametric change is given in Table 3.

Table-3: Response of static parameters due to damage at top face-sheet

| Boundary condition | Transverse deformation (max) (m) | | | Strain energy (max) (J) | | | Total equivalent strain (max) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Bot dam | Core-dam | Top-dam | Bot-dam | Core-dam | Top-dam | Bot-dam | Core-dam | Top-dam |
| a | 3.181 E-5 | 3.196E -5 | 3.203E -5 | 3.765E -4 | 3.515E -4 | 3.544E -4 | 1.435 E-5 | 1.453 E-5 | 1.445 E-5 |
| b | 1.417 E-5 | 1.419 E-5 | 2.118E -5 | 8.944E -5 | 8.552E -5 | 8.647E -5 | 1.269 E-5 | 1.269 E-5 | 1.266 E-5 |
| c | 5.934 E-6 | 5.439 E-6 | 5.080 E-6 | 1.086 E-4 | 1.205 E-4 | 1.095 E-4 | 1.345 E-5 | 1.346 E-5 | 1.344 E-5 |

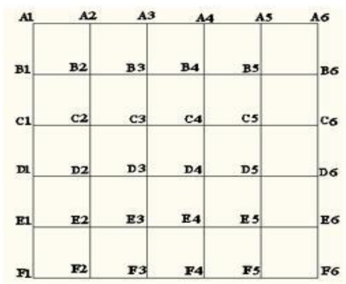
| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| d | 6.924 E-6 | 6.070E -6 | 6.093E -6 | 1.077E -4 | 1.211E -4 | 1.098E -4 | 1.411 E-5 | 1.413 E-5 | 1.403 E-5 |

An interesting thing is happenning here that max transverse deformation reduces when the damage is occurred at top face-sheet under the boundary condition a and b. As concrete doesn't have any tensile contribution the damage at top face-sheet results the reduction in transverse deformation not because of increasing in stiffness rather due to decrease in self weight as mass is reduced by damage. And it increases for the other two cases as top face-sheet is subjected to compression in these cases. The maximum total equivalent strain behaves in the similar way. But the strain energy is increased for all the cases of top-sheet damage may called as effective damage for strain energy.

Max transverse deformation doesn't differ much due to core damage for the case of a and b due to less structural contribution. But for the case of c and d flexural rigidity becomes less due to damage in that region which may affect the behaviour of the static property like transverse deformation at those region. Thus the max transverse deformation differs that much for last two cases. For first two cases the max total equivalent strain increases where it behaves just opposite in case of c and d. The most active damage is bottom-sheet damage for first two boundary conditions as bottom face sheet plays a lead role in compression for this condition. Thus any damage in that changes all the structural parameters forcibly. And also like the previous the transverse deformation is reduced as it acts at the tension zone for the last two cases and it is unable to contribute. So this damage doesn't increase the deformation rather decrease due to bring down the dead load. Max strain energy and total equivalent strain for the first two cases are almost unaltered but these differ much for the final cases. May be, the reduction of rigidity increases both strain and strain energy but reduction in dead load balances.

## 3.2 Sensitivity Analysis

The top face-sheet is marked by 36 nodes from A1 toF6 ,which is shown below and the sensitivity would be measured at only these locations .




Now damage is introduced by decreasing the E value at certain location of damage which affects all the static property but not necessarily at every node. The proposed technique for this particular mathematical model is elaborated here. 7 damage locations are chosen for this purpose namely 1) Damage at centre, 2) Damage at Left corner end 3) Damage at Right corner end 4) Damage at Left adjacent corner 5) Damage at Right adjacent corner 6) Damage at Left centre 7) Damage at Right centre. Damage locations 1-7 are shown below.

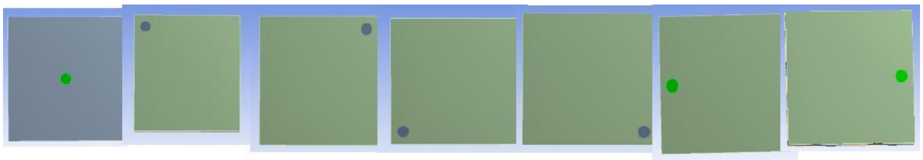


Fig 8: Different damage locations

A thorough analysis was done assuming boundary condition (a) taking transverse deformation as a static parameter. The percentage response of each node on the top face sheet is evaluated under differenet damage type and location on which basis a set of sensitive nodes (SSN) is selected for each damage type which is followed by the selection of common set of sensitive nodes (CSSN) for each damage loaction. And finally our aim is to gather the sensitive nodes for the structural set of sensitive nodes (SSSN).

The transverse deformation for each node is measured due to each type of damage namely i) top face-sheet damage, ii) core damage and iii) bottom face-sheet damage at location 1 and then finally is compared with that of undamaged one to evaluate the percentage change in static response. There after the nodes which had a response above a certain limit, of course which can be detected by the available instruments, have been collected for the set of sensitive nodes which would help in selection of Common set of sensitive nodes (CSSN) for the particular damage loaction later. For example response graph of sensitivity of nodes due to bottom face-sheet damage is represented below in fig.

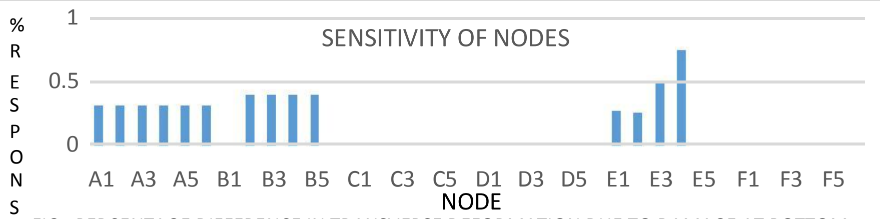


FIG : PERCENTAGE DIFFERENCE IN TRANSVERSE DEFORMATION DUE TO DAMAGE AT BOTTOM

Table-6: Sensitive nodes due to different type of damage at location 1

| Damage at | SENSITIVE NODES |
|---|---|
| Bottom face-sheet | A1-A6, B2-B5, E3,E4 |
| Core | A1,A6,B1,B2,B4,B5,C1,C2,C5,C6,D1,D3,D4,D6,E1-E6 |
| Top face-sheet | ALL except (F1-F6) |

From the above table it can easily be observed that there are six nodes at the top face-sheet which are sensitive for all type of damage at location (a). Common set of sensitive nodes (CSSN1): (A1, A6, B2, B5, E3, E4). Now using the same approach the sensitive nodes are chosen to build up CSSN for each damage locations.

Table-7: Sensitive nodes due to different type of damage at location 2-5

| Damage at | SENSITIVE NODES | | | |
|---|---|---|---|---|
| | Location-2 | Location-3 | Location-4 | Location-5 |
| Bottom face-sheet | D3,E5 | D4, E2 | ALL except E4 | ALL except E3 |
| Core | ALL except (D4,D5) | ALL except (D2,D3) | ALL except (D1,D2,A1) | ALL except (A6,D5,D6) |
| Top face-sheet | ALL except (D5,E6) | ALL except (D2,E1) | ALL except (B2,C4,D4) | ALL except (B5,C3,D3) |

Common set of sensitive nodes (CSSN2): (D3, E5),Common set of sensitive nodes (CSSN3): (D4, E2),Common set of sensitive nodes (CSSN4): (A2-A6, B1, B3-B6, C1-C3, C5, C6, D3, D5, D6, E1-E6),Common set of sensitive nodes (CSSN5): (A1-A5,B1-B4,B6,C1,C2,C4-C6,D1,D2,D4,E1,E2,E4-E6)

Table 8: Sensitive nodes due to different type of damage at location 2-5

| Damage at | SENSITIVE NODES | |
|---|---|---|
| | Location-6 | Location-7 |
| Bottom face-sheet | A1-A6,B2-B5,C1,D1,E1-E3,E5,E6 | A1-A6,B2-B5,C6,D6,E1,E2,E4-E6 |
| Core | A1,A6,B1,B5,B6,C1,C5,C6,D5,D6, E1,E3-E6 | A1,A6,B1,B2,B6,C1,C2,C6,D1,D2,E1-E4,E6 |
| Top face-sheet | A1-A4,B1-B3,C1,C3,D1-D4,E1-E6 | A2-A6,B4-B6,C4,C6,D3-D6,E1-E6 |

Common set of sensitive nodes (CSSN6): (A1, C1, E1, E3), Common set of sensitive nodes (CSSN7): (A6, C6, E4, E6)

Now it can be observed easily that there is no node on the top face sheet available at all common set of sensitive nodes (CSSN). Thus a multiple number of nodes must have to be selected to get assurance whether damage is taken place in the structure. Also the set of sensitive nodes for the whole structure can't be chosen arbitrarily because we need to pick the nodes in such a way that a minimum number of nodes get selected on the basis of priority of sensitivity for maximum damage locations. Thus a thorough analysis was done in MATLAB to find the most efficient set of sensitive nodes where the node which is sensitive for maximum number of damage location gets preference first and so on. For this above mentioned mathematical model the set of sensitive nodes for the whole structure which is hereby denoted as structural set of sensitive nodes (SSSN) should be chosen in between these two sets namely (A1,A6,D3,D4) and (A1,A6,E2,E5). Thus the graphical representation of the sensitiveness of two sets shows us that both of these two are good enough as SSSN.

But it would be wise selection if we choose the second set as our most wanted SSSN as damage at location 4 and 5 can be detected by one more node. And furthermore studies will show that it would be preferable to select the second set for the damage detection through inverse approach as it will give more number of response to the sensitivity matrix.

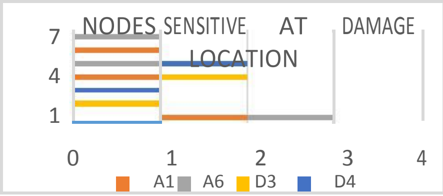



Fig 9: Sensitiveness of 1st set of SSSN

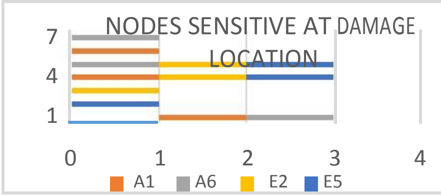



Fig 10: Sensitiveness of 2nd set of SSSN

## Conclusions

Based on above numerical study of polystyrene based sandwiched composite model it can be confirmed that static characteristics are influenced largely due to any damage at any location. Though the core is not assumed as an efficient structural material it also affects the static parameters up to a large extent for few cases. Secondly as the nodes for sensitivity analysis are chosen only at the top face of the panel for simplicity the damage at bottom concrete is less detective by them. More specifically the bottom concrete damage detection is becoming poor with the increase of distance of damage location from its support end. More no of nodes may produce more attractive result. The procedure discussed in this proposed paper also would work taking strain energy as static characteristics as strain energy as it gets affected much. The second part of the proposed paper, selection of sensitive nodes will also applicable as measured nodes to evaluate the parameters by inverse approach. However more study should be needed to make the process generalize for every possible support condition.

## References

[1] Maciej Radzieński, Marek Krawczuk, Magdalena Palacz, "Improvement of damage detection methods based on experimental modal parameters", *Mechanical Systems and Signal Processing*, Volume 25, Issue 6, August 2011, Pages 2169-2190.

[2] D. Bandyopadhyay, Anubhav Roy, Arka Dey, "Computational Study of Structural Insulated Polystyrene Reinforced Concrete Sandwich Panel for Energy Efficient Building Construction", *International Conference of Theoretical, Applied, Computational and Experimental Mechanics Proceedings* (2014). [3]A. Benayoune , A.A.A. Samad , A.A. Abang Ali , D.N. Trikha, "Response of pre-cast reinforced composite sandwich panels to axial loading", *Journal of Construction and Building Materials,* (2007) Vol. 21,pp 677-68.