FINITE ELEMENT MODELLING OF CONCRETE SANDWICH EPS PANELS UNDER VARIOUS LOADING CONDITION

A Thesis Report submitted in the partial fulfillment for the award of the degree of

MASTER OF ENGINEERING

IN

STRUCTURES

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DECLARATION

I, Pranav Khanna, hereby declare that the work which is presented in this thesis entitled "***FINITE ELEMENT MODELLING OF CONCRETE SANDWICH EPS PANELS UNDER VARIOUS LOADING CONDITIONS***" in partial fulfilment of requirements for the award of the Master of Engineering in Structural Engineering, submitted in the Civil Engineering Department, Thapar Institute of Engineering and Technology, Patiala, is an authentic record of the work carried out by me under the guidance of Dr. Naveen Kwatra, Professor, and Dr. A.B. Danie Roy, Assistant Professor, Department of Civil Engineering, Thapar Institute of Engineering and Technology, Patiala.

The matter embodied in this thesis has not been submitted in part or full to any other institute or university for the award of any degree.

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CERTIFICATE

This is to certify that the above declaration made by the student concerned is correct to the best of my knowledge and belief.

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ABSTRACT

Throughout the world with the improvement in the standard of living and growing population need for quality housing is increasing day by day. To fulfil the need for housing and to build infrastructures such as hospitals, schools, colleges, corporate buildings, bridges, roads, etc. The over-exploitation of natural resources such as building materials which act as building blocks in a building is becoming a serious problem. Today the natural resources like sand, clay, aggregates, etc. are depleting at a fast rate to full fill the needs of the present construction industry. Hence research is going on to develop new materials which can replace convention building materials without affecting the structural quality for promoting sustainable construction. One such material is Precast Insulated Concrete Sandwich (PICS) panels for acting as load-bearing walls and slab in building systems. Use of precast insulated concrete sandwich (PICS) panels is cost effective and time-saving. In this context, precast concrete sandwich panels having two wythes separated by a core may serve dual purposes of transferring load and insulating. The objective of this study is to basically describe the various sandwich panels used in construction, their classification, their performance based on previous studies and their applications as load-bearing wall in the building construction. The most commonly used panels are concrete EPS panels which are described in detail in this study. Further, the core material can be replaced with other economic materials like aluminium alloy based corrugated core, a GFRP, CFRP, etc. Use of different types of connectors is discussed in detail based on the previous studies. Some of the limited available research results based on experimental and analytical investigations are discussed. This thesis presents the results of FEM analysis of precast insulated panels sandwich between concrete under flexure, punching, push-off loading, axial and diagonal compression loading. The FEM analysis of the panels is done by Ansys Workbench software by considering nonlinear behavior. This thesis is divided into two parts. The first part deals with the FEM analysis of slab panel for flexure, punching and push- off loading and the second part shows the behavior under axial and diagonal compression of structural load bearing wall panel. At last, the deformation behavior of the panels is highlighted which is validated with the published experimental results of various authors. For the analysis ansys static tool is used and the analysis is done implicitly using edge split condition for applying force and boundary conditions.

Keywords: PICS (Precast In situ Concrete Sandwich), panels, flexure, punching, push-off, axial, diagonal, compression, FEM (Finite Element Modelling), ANSYS WORKBENCH.

TABLE OF CONTENTS	PAGE NO.

TABLE OF CONTENTS	PAGE NO.

TABLE OF CONTENTS	PAGE NO.

TABLE OF CONTENTS	PAGE NO.

List of Tables

Page No.

LIST OF FIGURES

Page no.

LIST OF ABBREVIATIONS

DCA	Degree of Composite Action
PICS	Precast In situ Concrete Sandwich
NRM	Newton Raphson Method
MNRM	Modified Newton Raphson Method
EPS	Expanded Polystyrene
XPS	Extruded Polystyrene
f_{ck}	Compressive Strength
E_c	Modulus of elasticity of concrete
FEM	Finite Element Method
FEA	Finite Element Analysis
E_{sh}	Hardening modulus of steel
E_s	Modulus of elasticity of steel
σ	Stress
€	Strain
f_{cu}	uniaxial comp. resistance to deformation
f_t	uniaxial tension resistance to deformation
f_{cb}	biaxial comp. resistance to deformation

Chapter 1: INTRODUCTION

1.1 GENERAL

India is the fastest growing and highly populated country. With the growth of the country, the need for infrastructure increases. Hence to fulfill the need of infrastructure and to provide housing to all till 2022 which is the mission of the government of India in a given frame of time work it is not possible with the use of conventional building materials. As the conventional methods of construction are more time consuming and cost increasing but also, the natural resources like sand, clay, aggregates, etc. are depleting at a fast rate to full fill the needs of the present construction industry. So, the researchers are moving toward developing new construction techniques. By moving in that approach, the concept of research of new building materials arises which are not only time saving but also cost-effective without compromising with the structural requirements that are high resistance to deformation, durability, serviceability, and deterioration with time. One of such materials is Precast In situ Cement matrix Sandwich (PICS) boards which are going to be popular all these days in the world. These boards are produced under controlled factory circumstances hence are good in finishing and accurate in geometry. PICS boards are light weighted in nature hence are less attractive to seismic forces, easy to handle, transport and cost-effective. Thus, beneficial to society and the environment [Yee. AA (2001)]. PICS boards are lightweight due to the reason they are manufactured by replacing the inner middle sheet with a less dense insulated material middle sheet such as of Expanded polystyrene (EPS), extruded polystyrene (XPS) or wooden plank at the center which provides sound and thermal isolated. The insulated middle sheet is skinned by cement matrix (concrete) wythe on both sides such that the cement matrix wythe (concrete) are separated by EPS middle sheet and the 2 outer sandwich layers are linked together with shear linkers as result of which the boards seems like a sandwich. Therefore, these boards known as sandwich boards. [Yee. AA (1984)].

Hence, in a nutshell, these boards can be divided into 5 components that are

A. Outward cement matrix (concrete) wythe.
B. The middle sheet of EPS material.
C. Shear connectors
D. Inward cement matrix (concrete) wythes
E. The welded reinforcing mesh of high strength. as shown in figure 1.1

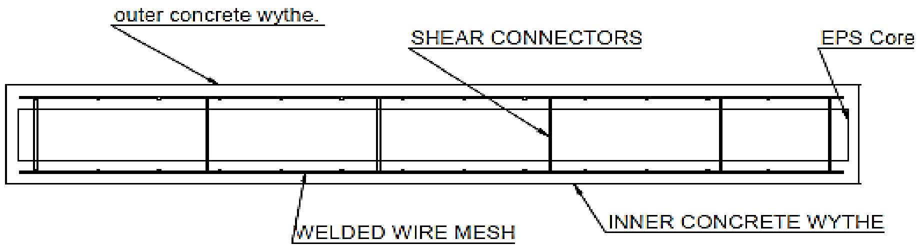

Figure 1.1: Components of PICS boards

1.2 HISTORICAL BACKGROUND OF SANDWICH BOARDS: -

Despite the very fact that foam boards picked up notably large attention throughout the Nineteen Seventies, utilizing stress scraped boards for development started throughout the 1930s. To preserve natural timber assets this innovative technique was developed in Madison, Wisconsin as a component of U.S. Forest Service by Forest product Laboratory (FPL). In 1937, a little low stressed-casing building was made and noticed by herald 1st woman diplomat. In an exceedingly proof of the durability of board buildings, its tolerance serves the Wisconsin environment and was utilized by the University of Wisconsin–Madison as daily basis maintenance center till its demolishment for the creation of a brand-new Pharmacy faculty structure. The achievement of these strain scraped boards, it's been told that maximum load carrying is only due to the outer skin and the central layer can be replaced either by low-cost material or kept vacant for material saving.

Hence in 1947, PICS board advancement started once furrowed composition board centers were, they tried with completely different casing ingredients of ironed wood, hardened chipboard, and cured poster board. This structure was demolished in 1978 and many boards maintained their previous high resistance to deformation with the exclusion of poster board that is mismatched to outside contact. Boards comprising of EPS center and paper coated with compressed wooden casings were utilized during in structure in 1967 and working good till date.

1.3 X-SECTIONAL DETAILS OF PICS BOARDS: -

PICS board are rectangular measured industrial plant created boards, made with low-density EPS sheet with sandwiched between 2 intended welded wire cloth mesh, manufactured from high resistance deformation wire of 0.25 centimeter - 0.3-centimeter diameter. A 0.3 centimeter to 0.4-centimeter truss wire is penetrated completely inside central middle sheet to counterbalance the plot for higher quality and also the attachment is completed at each node wherever the steel welded wire mesh and also the shear linkers are meeting. The final finishing of these boards' is done at the positioning using dense shotcrete at high force. This final touch encases the Middle sheet with welded wire cloth mesh. Figure 1.2 shows a 3D X- section of PICS boards.

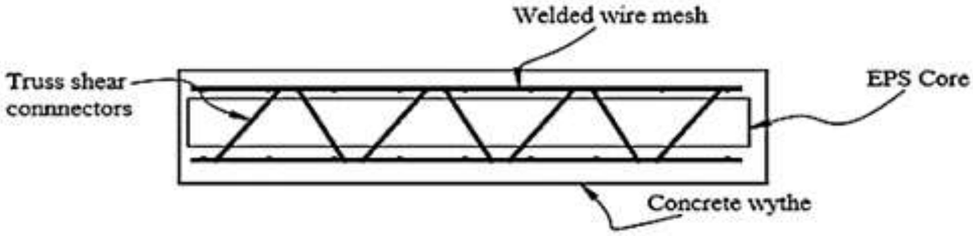

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Figure.1.2: Representative 3-D X section

1.4 APPLICATIONS OF PICS PANELS: -

The 1st use of these PICS boards is done as non-bearing functional member known as "cladding board" (A Einea) then after the use of these boards are explored to various purposes. Nowadays there are used for residential, commercial and warehousing infrastructure both as well as a slab. (Precast Concrete Institute (PCI) committee). Presently the work of construction with PICS panels is going on the higher rate in countries like USA, Canada, Europe, UK, etc and the trend is increasing day by day.

1.5 ADVANTAGES AND DISADVANTAGES OF PICS BOARDS: -

I. Reduces the total construction expenses

II. Reduces time of project completion

III. Reduces conveyance price because of its low density these boards: The fitting ensures no heavy building apparatus.

IV. Both thermal and sound insulation is provided.

V. EPS 3-D boards save the cost of soil preparation since no special excavation or ground improving technique is required.

VI. Having high intermolecular bonding and resistance to wear and tear.

VII. Besides these advantages, these boards are not coming day to day construction practices because these boards are manufactured by a limited number of companies in India. Also, the construction requires skilled labour which is not available till date because the labour is skilled in conventional construction practices. There is less awareness about these technologies in the builder. Hence, today the trend of PICS board construction system is very limited but the future of this technology is bright.

1.6 NEED FOR THE STUDY: -

As the construction of precast in-situ concrete sandwich panels is very laborious and tedious process. In addition to cost factor, availability of the core that is EPS in different thicknesses and different densities is in itself a task considering the research aspect. Experimental setups required to test such panels is very costly. To study various parameters to have an overall behaviour many samples has to be cast and tested. Therefore, the main disadvantage of experimental method is the cost and time related to it. So, it is better to see for an alternative method which is equally good.

The technological advancement has opened many alternatives, such as finite element methods are capable of providing the analysis for such boards (PICS). The results obtained from FE analysis are well capable of predicting the performance of these panels with the diffference of less than 10-20%. So it saves the labor, time and as well as the costly experimental setup expenses.

1.7 IMPORTANCE OF FEM ANALYSIS: -

As the experimental work is time-consuming and relates a lot of costs since for experimental analysis high accuracy is achieved only and only when the sample size of the experiment is very huge. For empirical analysis, a lot of knowledge of mathematics is required for getting a Non-Linear solution to the problem. Even though getting a nonlinear solution is not the guaranty of accuracy since a lot of uncertainty is correlated with the empirical methods. Therefore, FEA methods provide a key to the lock of drawbacks associated with experimental and numerical methods. But for measuring the accuracy of the prototype a validation is required which correlates the FEA simulation with the actual experiments. Hence, FEA models reduce the extra effort required for the experimental analysis. But for efficiency in the prototype right input of the required model values is necessary. Hence, carefulness is required while inputting the required field values.

1.8 SIGNIFICANCE AND OBJECTIVES OF STUDY: -

The significance of the work is to study the performance of PICS boards under flexure, punching, push-off loading., axial and diagonal compression loading cases. The study of these loading cases is important because flexure and punching are the main loading cases which are occurring in the slab. Hence the analysis of pics boards is important for these dominating cases of loading in the slab. Push-off loading case occurs when a shear load is applied to the slab board which happens when a load is transferred from wallboard to slab board through slab and wallboard joint under lateral loading in practical case due to wind or earthquake loading and axial compression and diagonal compression are main load cases that are occurring in wall boards and these boards are acting as a load bearing wall. So, a rigorous study is needed to be done to evaluate how different is the functioning of these boards from the actual building wall. The objectives are as follows:

- Behavior of Precast In-situ Concrete Sandwich boards board acting as slabs under different loading conditions viz, flexure, punching shear and push-off by using Finite element method.

- Analytically observing the behavior of Precast In-situ Concrete Sandwich boards as wall panels under axial and diagonal compression loading.
- To validate the analysis under different loading cases with the published experimental research.

1.9 OUTLINE OF THESIS: -

This thesis is split into five chapters and is ordered as per structured given below:

Chapter 1: Familiarizes to the subject of debate briefly.

Chapter 2: Discourses the work done by varied researchers within the field of EPS boards as structural members.

Chapter 3: It deals with theory related to the ANSYS, material prototype geometric configurations, cement matrix coefficients, boundary conditions. 1st part deals with the FEM prototype of slab board, second part comprises of structured of wallboard but before these two parts, the theory related to the ANSYS, material prototype, geometric configurations, cement matrix coefficients, boundary conditions elemental properties are discussed.

Chapter 4: After the FEM analysis the results comes in are presented after that is validation with the published results of various authors whose name and reference are mentioned in the after chapters. The validation is only possible because of the conditions and properties taken for the analysis are the same as that of the published articles.

Chapter 5: At last the noticeable conclusions & proposals of this study are given during this chapter followed by the references.

Chapter 2: LITERATURE REVIEW

In this chapter, the general summarized the opinion of the research work that was carried out by various researchers to date to study the behavior of PICS boards is presented. All types of structurally insulated boards were considered during the research. The PICS boards were studied for both the purposes as structural as well as non-structural boards. From structural it means from slab and wallboard and from non-structural it means only partition wall. The structural member related to loading taking capacity and non-structural means having no load bearing capacity.

The study on PICS boards focuses on the slab as well as wallboard properties. For slab sliding shear, flexure and punching are the main role players and in-wall axial, eccentric and diagonal compression are the leading forces. Hence, it becomes important to study these structural boards so that the can fit for all purposes of the house construction and also they are compatible with weather states just like the conventional building materials so that our purpose of rapid eco-friendly construction gets fulfill without compromising with the actual structural requirements so that we can give a new kind of framework for this type PICS board construction and reduce the carbon footprint for our future generations, helps the mother earth from the global warming, air, water and land pollution without compromising with the structural resistance to deformation requirements. By moving with this agenda, a literature review of the type of system of construction is given in this thesis.

2.1 STRUCTURAL FEATURES OF PICS SHEETS: -

Prior to considering the works administered by individuals across the globe, on EPS boards a part of PRECAST CONCRETE INSTITUTE (PCI) Committee Report (1997) on formed Sandwich Wall boards is presented in this thesis since no study is completed without the discussion of this report. The most points of the report area unit mentioned in this thesis reports how the manufacturing of these boards is done, the various types of structural components used for the manufacturing, what is the properties of those structural member, how these components get assemble to form a single unit, how that single unit get adjusted in that environment and how that board works like force distribution in the board, force transmission, reaction to the forces and the behavior of the board with different cores and skins. The knowledge of all that valuable information is necessary for studying the board performance. The Precast Concrete Institute (PCI) report also give the estimated response of the boards subjected to varied forces.

To achieve the structural potency is the primary aim of PICS boards. By the fusion of thin, firm, inflexible and robust plasters on both sides of the thick, low density, end to end connected middle sheet a birth is given to high resistance to deformation, rigidity structural member. This amalgamation of geometry not only provides robust board casing but also immunes the board from bending, resistance to edgewise loading, and resistance to racking, The PICS boards may be classified in the main into 3 classes that are relying upon the structural behavior as:

A. Composite boards: The full transfer of load gets performed from edge to edge of the board. The value of DCA is 100% for the members. Figure 2.1 shows strain behavior.

B. Partially composite boards: The partial transfer of load gets performed from edge to edge of the board. The value of DCA is 0% to 100% for the members. Figure 2.1 shows strain behavior.

C. Non-composite boards: These boards do not act as a single unit instead of isolated structural layers. The transfer of load is limited to a single layer only. Figure 2.1 shows strain behavior.

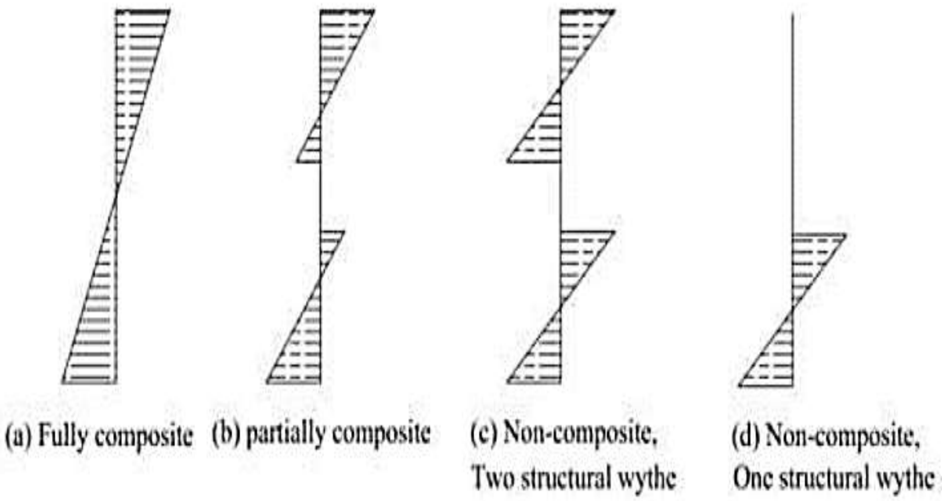


Figure. 2.1: Strain distribution in Sandwich boards, PCI Report (1997)

2.1.1 Casing Linkers: -

Linkers in PICS panels help the board middle sheet to get hookup with cement matrix casing to utilize the potential of the boards by the saving of the inner material. Board strength is mainly relying upon the resistance to deformation and strength offered by shear linkers. As per the guidelines of the PCI report (1997), the main characterization of the board is as follow.

2.1.1.1 Linkers utilized in PICS boards: -

The functional importance of shear linkers in PICS boards is to achieve the highest possible composite action and such that the maximum transmit shear through the covering casings gets possible. Differing kinds of linkers are utilized in the past decades. Depending on the conduct of the linkers, linkers are also cataloged as:

1. Shear linkers: Shear Linkers are accustomed to transfer longitudinal shear, leading to transfer of load from one wythe to the opposite. These linkers could resist shear in one or 2 perpendicular directions.

I. Unidirectional shear linkers:

a) targeted unidirectional Linkers

b) Continuous unidirectional Linkers

II. Bidirectional shear linkers: These linkers have the comparable shear capability in two directions within the plane of the board.

A) Cylindrical sleeve anchors: These Linkers are robust in counterattacking torsion similarly as shear. They're meant to be used in non-composite boards to transmit the pressure of the non-structural wythe to the structural wythe.

B) Crown anchors: They're created by bending tiny diameter bars into a 3-dimensional configuration.

C) Cement matrix blocks: These blocks are meant to enclose the board lifting inserts. a number of the unidirectional shear linkers are shown in Figure 2.2**.**

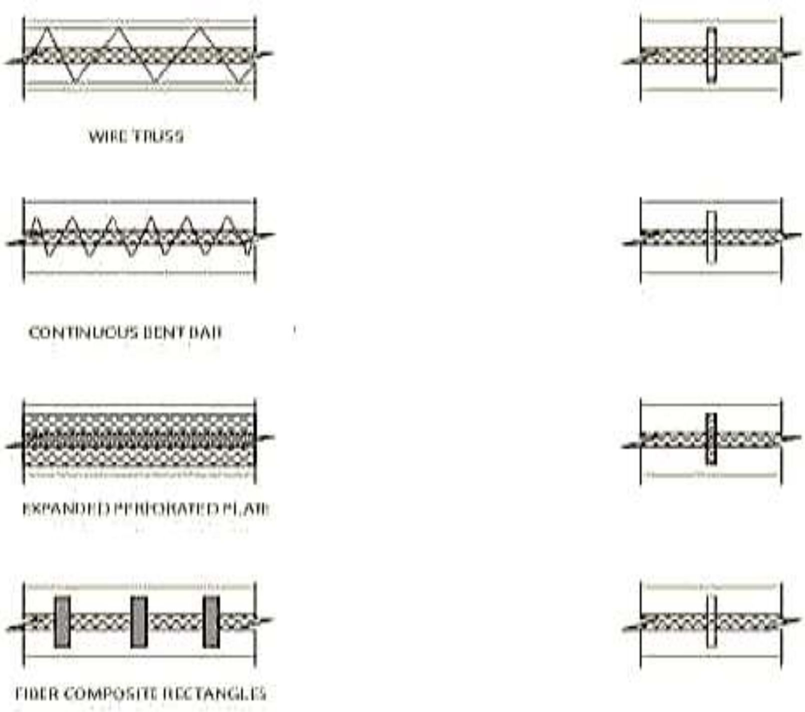


Figure. 2.2: Unidirectional shear linkers, PCI Report (1997)

2. Non-shear linkers: A little or no quantity of longitudinal shear from one layer to the opposite get transmitted by the use of these linkers. They're mainly functional in non-composite boards to transmission tension or compression forces. They are mainly metallic and non-metallic linkers.

I) Metal made linkers: They're Fe bars of galvanized or stainless- bent into numerous arrangements. Correct anchorage into each cement matrix casing is completed through deforming or draw at the pin ends. Continuously welded ladder linkers are used as non-shear linkers. they're akin to equally spaced pins.

II) Non-metal made linkers: These linkers are fabricated from non- bolstered or fiber powered plastics. The utilization of plastic pins is also beneficial in evading condensation at instrumentation locations within buildings wherever the humidness is high.

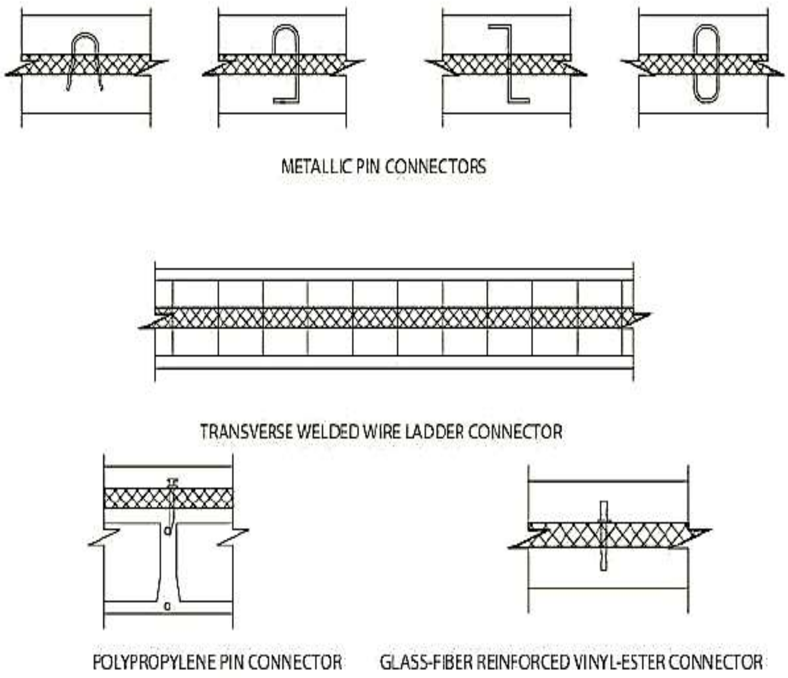


Figure. 2.3: Non Shear Linkers, PCI Report (1997)

If boards are manufactured by means of any material other than cement matrix, then the composite action is attained by proper adhesion of the skins with the middle sheet using adhesive materials like epoxy.

2.1.2 Isolated middle sheet

Just like any other manufactured product the properties of the isolated layer primarily depend on their erection, the crude materials utilized and therefore the collection procedure. The thermal properties are of utmost vital for the choice of an appropriate thermal isolated middle sheet. Practicality and safety of the building are vital criteria which is a function of resistance to deformation, durability, sound isolated properties, and resistance to wetness and hearth. the choice of an isolated kind to reinforce energy performance is as vital because of the reinforcement required to reinforce structural performance. The resistance to deformation of middle sheet material is mostly low however altogether with low density because of its bigger depth, the PICS boards got high bending strength. Production of the thermal insulation layer is mainly of two types.

Thermoplastic: Easily distorted on heating and bent without difficulty. The layers of polystyrene formed called shaped expanded polystyrene (beadboard) and extruded expanded polystyrene (extruded board).

• **Thermosetting:** Difficult to distort and change the shape of heating. These isolated layers include polyurethane, polyisocyanurate, and phenolic

2.1.3 Mechanical casings: -

The mechanical casings act as the main load carrying components of the PICS boards. The casing should be able:

• For load bearing wall it conveys the compressive (compression) forces acting on it and for walls subjected to out of plane its main work is to transmit the tensile. (tensile) and compression forces if bending occurs.

• To provide a suitable bond with the isolating middle sheet material and to deliver security to the middle sheet material from fire.

In the case of cement matrix boards, the functionality decides the structural depth of the top and bottom cement matrix casing.

2.2 METHODS OF ANALYSIS OF PICS BOARDS: -

The analysis of PICS panels is mainly divided into three parts as considering the published literature that is:

2.2.1 EXPERIMENTAL INVESTIGATION

2.2.2 NUMERICAL INVESTIGATION

2.2.3 FINITE ELEMENT ANALYSIS BASED INVESTIGATION

All these techniques are discussed one by one as follows.

2.2.1 Experimental investigation: **-** Various researchers have performed various experimental results to found the behavior of cement matrix composite panels. Out of the performed experiments, the brief writeup is given. The studies are done to judge the real environment behavior of the panels in actual conditions. These tests were performed under certain standard guidelines following the present codes. The fulfillment of the guidelines is important so that a uniform standard is followed and these results lead to conclusive discussions. If these results not get followed the standards the no conclusion can be driven out from the tests. Referring to the reference articles the standards of the tests are as follow. The standardization of material is also very important besides the test standardization along with the control of the preferred environmental conditions. The test standards are as follow.

2.2.1.1 Flexural and punching behavior of sandwich board: -

For flexure: - The standards of **ASTM E518-10** are followed by the researchers to conduct the experiment. The board is act as a unidirectional board with one support hinge and another support roller.

The name given to the loading by the code is 4- point bend test. The test is similar to RC slab testing in flexure. The experimental setup is shown in the figure below.

Figure 2.4: Four- point bend arrangement for the experiment (Daniel et.al (2018))

For punching: - The standards of **ASTM E2322 – 03** followed by the researchers to conduct the experiment. The board is act as a unidirectional board with one support hinge and another support roller besides of its square shape. The name given to the loading by the code is a concentrated load test. The test is similar to RC slab testing in punching. The experimental setup is shown in figure 2.5 below.

Figure 2.5: Concentrated load arrangement for the experiment (Daniel et.al (2018))

Salmon et al. (1997) led full-scale trials on erect samples of sandwich boards of height 900 cm with FRP linkers and steel truss linkers. The main agenda of the work was to examine the behavior of boards exploitation completely different material aside from steel. They found that the employment of recent material FRP as shear linkers for the outer and inner cement matrix casings provided comparable final resistance to deformation to the resistance to deformation expected from the absolutely composite board. They conjointly conducted flexural tests on tiny scale formed cement matrix sandwich boards of length 244 cm with one row of FRP bent bar through the middle line of the board. The tests provided an estimate of the quantity of composite action provided by the FRP connecter. The load-deflection curves were comparable the analytical solutions and also the finite element prototype.

Benayoune et al. (2008) examined the structural performance of boards with truss form Steel shear linkers for flexure and examined the potency for its character in confirming composite functioning. For this, they used 3 varieties of boards of larger to smaller dimension ratio as 2.67, 1 and 2 and of size 2000mm X 750mm, 1500m X 1500mm and 1000mm X 500mm that works as a bidirectional and unidirectional slab. Each the borders of the polystyrene middle sheet of 4cm are plastered with Cement matrix layer of 4 cm is provided on both sides. For a mesh of 10cm x 10cm a 6mm diameter, Steel has been used. A spacing of 25cm is provided for truss shear linkers. The highlighting of the board with white color is done so that the crack patterns become noticeable. For unidirectional slab, it had been supported on 2 shorter sides and for bidirectional slabs were supported on four sides under flexure. The experimental results the plot load deflection profile, strain variation across the block depth and strain in shear linkers is mentioned. From the load-deflection profile, it seems that before the primary cracks that appeared in cement matrix the boards were behaving elastically thus the load pattern was linear and the behavior turns non-linear once the primary crack occurs and also the deflections enhanced considerably until failure.

Sohal K.M.A et.al (2011) deliberate tips based on the analysis in an analytical, mathematical and tentative explored study on Steel-cement matrix (SCS) sandwich structural members together with a low-density cement matrix middle sheet exposed to static, impact and blast forces. The performance of low-density members is additionally compared with alike members with normal weight cement matrix middle sheet and ultra-high-performance cement matrix middle layer (fc = 180 MPa). Innovative J-hook shear linkers were created in use to avoid the separation of face plates from the cement matrix middle sheet subjected to extreme masses and their application don't seem to be restricted by the cement matrix middle sheet thickness.

They over that, SCS sandwich boards with J-hook linkers exhibit ductile behavior after they are subjected to flexure and punching loads. the employment of J-hook kind shear linkers impassively improves the punching and impact resistance of cement matrix middle sheet because of the confinement effect. The J-hook shear linkers stop the native buckling of the face plates and enhance the resistance because of tensile separation of the face plates. To predict failure modes an analytical solution has been planned that ascertained the tests together with punching shear failure, shear linkers failure, flexural and yielding of Steel Plates. If the patch load is applied in a little space, punching failure was found to be the dominant mode of failure. The J-hook connector was found to be effective not solely in resisting the cross shear however conjointly the vertical shear. using the plastic yield line analysis, abound solution for predicting the ultimate flexural resistance to deformation of SCS sandwich slabs are often obtained.

J. Daniel et al. (2016) investigates the performance for punching and four-point bending of PICS boards. They used self-compacting cement matrix that having slump >65 cm. For this they used 2 boards of the scale 122cm X 122cm X 15cm and 300cm X 122cm X 15cm having an aspect of the EPS wire web is employed of 10cm X 10cm that are linked by the truss form Steel shear linkers that are inclined at 45^0 and wires of the mesh and shear linkers are of 0.22 cm diameter. The results of the experiment are attained within a variety of force-displacement and moment-displacement graphs. once the board was exposed to punching force a flexure mode of failure is ascertained and once the board is exposed to flexural loading a failure was detected because of the collective consequence of shear and flexure stress.

2.2.1.2 Compression behavior of sandwich boards

For axial compression: The standards of **ASTM E2954 – 15** followed by the researchers to conduct the experiment. The board is act as a wall with bottom support as fixed and the top edge support is a hinge. The name given to the loading by the code is Axial load test. The test is similar to wall testing in various edge support condition. The experimental setup is shown in figure 2.6.

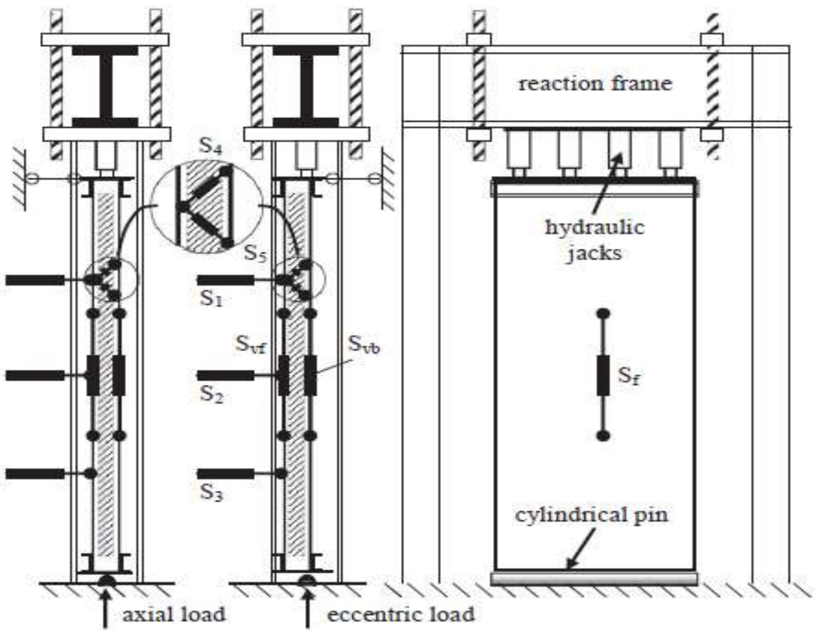


Figure 2.6: - Testing of PICS board in Axial and eccentric compression (Gara et.al (2012))

The studies carried by numerous researchers bent on to investigate the axial compression behavior finds that the axial compression behavior of these panels mainly relying upon the fabric used to construct the boards.

Benayoune et al. (2005) experimentally studied the ultimate resistance to deformation behavior of PICS boards below the impact of eccentric loading having truss shear linkers of steel. The duty of shear linkers use was to transfer load from the environmentally exposed layer to the indoor layer and to give assurance of the highest possible degree of composite action (DCA). A 38 % increases in the ultimate resistance to deformation is observed with the 100% decrease in the resulted value of slenderness ratio. The variation of deflection along the height of PICS board shows the composite action is taking place in the board from the indoor to outdoor cement matrix layer and the boundary condition is taken as the bottom face is fixed and the top edge is hinged.

Gara et al. (2012) Experimentally performed the analysis on EPS middle sheet boards encompassing with Steel wire net on each side with non-shear linkers linking cement matrix skins on each side and the reinforced beam was created at board ends. For different slenderness ratio, they apply eccentric and axial masses beneath the compression tests board wall to review their conduct beneath vertical forces (in-plane forces). The boards perform a semi composite owing polystyrene middle sheet and RC end support beams. The determination was that the ultimate load carrying capacity will increase, by the decrement within the slenderness ratio. Just in case of axial loading the ultimate masses were near to buckling forces and within the case of eccentric loading, the ultimate masses were considerably under buckling forces.

Therefore, it is evident from the results of the investigative trial and mathematical analysis that the boards perform partial composite conduct no matter whether or not what type of shear linkers were used, this incomplete composite action was due to middle polystyrene layer. In conjugation with reinforced solid RCC beams at the finishes.

Smakosz and Tejchman (2014) sequentially trialed on boards manufactured of EPS foam middle sheet and optical fiber facings resistance to deformation and magnesium-cement to examine the resistance to deformation, deflection, and failure mode of within the compression tests, the failure was because of the crushing of the facings and no buckling was realized.

2.2.1.3 Diagonal shear behavior of sandwich boards:

For diagonal compression: **-** The standards of **ASTM E519/ E519 M-10** followed by the researchers to conduct the experiment. The board is act as a wall with bottom corner support as fixed and the top corner is loaded with a uniform loading rate. The name given to the loading by the code is a diagonal load compression test. The test is similar to wall testing on diagonal of the wall in compression and other in tension. The experimental setup is shown in figure 2.7.

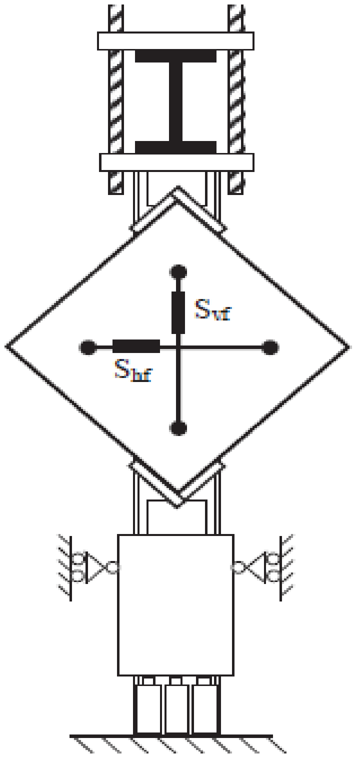
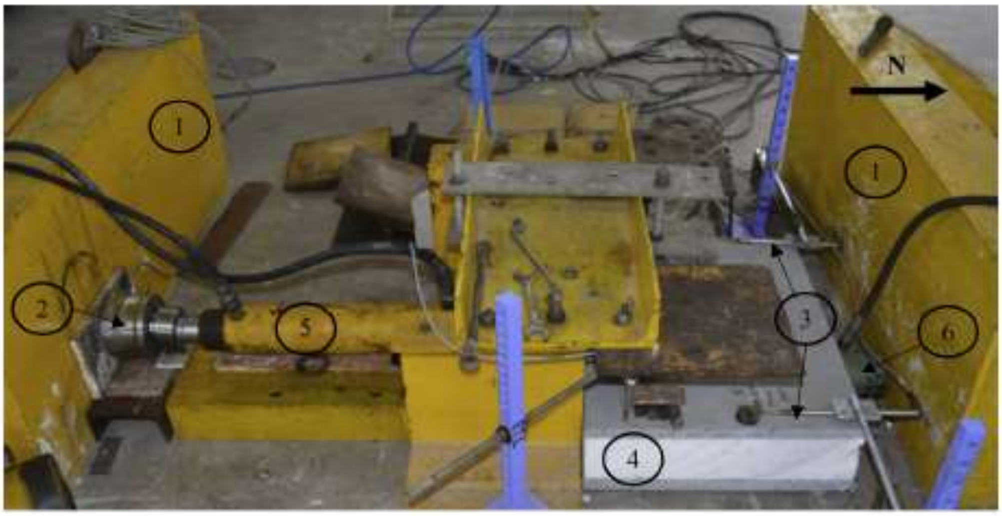


Figure 2.7: - Testing of PICS board in diagonal compression (Gara et.al (2012))

Gara et al. (2012) experimentally did diagonal compression valuation on equal sided quadrangle boards having totally different configurations to check their conduct below horizontal in-plane forces. The boards tested were having cement matrix casing with EPS middle sheet and welded wire web supporting the middle sheet on either side connected by pin or non-shear linkers on either side of the EPS middle sheet. Within the diagonal compression examinations, straightforward wall boards, and boards with transverse strengthening walls were tested. Simply one example with transverse strengthening walls had a tensile diagonal rupture rest different example incontestable a compression failure within the force application region. The FEA 2D mockup on the specimen shows the tensile diagonal rupture and therefore the final load is also valued on the bottom of the cement matrix tensile resistance to deformation.

2.2.1.4 Push off analysis of slab boards: -

For shear sliding or push-off loading: - The guidelines of the test setup are as per the test previously performed by **Einea A et.al. (1994)** followed by many researchers to conduct the experiment. The board is act as a rectangular slab with a shear load applied on the top face and bottom face is kept fixed. The name given to the loading is to push off shear loading. The advantage of this test is that gives the behavior of the board in lateral loading. In actual circumstances, this scenario arises either when the slab is subjected to wind or the earthquake load. The experimental setup is shown in figure 2.8.



1. Reaction Frame; 2. Load Cell; 3. LVDT; 4. Precast CSP Specimen; 5. Actuator to apply Load on Top Wythe; 6. Actuator to restrain Bottom Wythe.

Figure 2.8: Push offloading arrangement for the experiment (Daniel et.al (2019))

Shams et al. (2014) Examine the conduct of PICS board structural cement matrix members by the use of foamed polyurethane and elite cement. The authors found an enormous plausibility by utilizing these sorts of auxiliary components as rooftop and another divider basic individual structural member. They conveyed investigative examinations on the load-bearing conduct of PICS segments with material resistance deformation cement and ultra-superior fiber fortified cement (UHPFRC) just as changing sorts of linkers and foam centers. They reasoned that the PICS boards without connector components demonstrate an abrupt force drop prompting fragile failure. The utilization of shear linkers prompts an expansion in malleability and most extreme shear load, just as a high remaining limit after bond failure between the center foam and solid layer. The utilization of CFRP framework brought about a specific progression in most extreme shear load and prompts ductile conduct. In the shear tests, an augmentation in greatest loading just as higher plasticity could be seen by utilizing a shear grid. This is because of a tendency of 45° inclination of shear linkers. The stick linkers additionally prompted an expansion in the greatest shear load carrying capacity and plasticity.

J. Daniel et.al (2019) observed the effect of depth of isolated middle sheet, vacant space among the casing's absence/ presence of the isolated middle sheet and number of shear linkers lines in a line by through-depth shear behavior and resistance to deformation of the PICS boards. They stated that the through-depth shear capacity of the PICS boards decreases with the increase in the depth of the isolated middle sheet and increase in the vacant space between the cement matrix skins. The size of wire meshes is 100×100mm used for strengthening the casings of the PICS samples. EPS middle sheet of density 16 kg/m^3 was used. The top and bottom wire meshes were linked by the application of truss shape steel shear linkers of 2.2mm diameter Steel wires with an average tensile resistance to deformation of 651 MPa. The same configuration is for Steel welded wire mesh. The truss-type shear linkers are inclined at an acute angle (θ) of 70° with respect to the spanning or horizontal direction of the PICS samples.

The inclined members infiltrated through the isolated middle sheet and then the welding is done at the nodes of top and bottom wire meshes. The top and bottom cement matrix skins of the PICS boards were created using BFSSS Cement matrix (SCC). The mean compression and tensile capacity of the BFSSC cement matrix were taken to be 46 MPa and 4.35 MPa respectively.

2.2.1.5 Durability of PICS wallboards:

Kazem et al (2015) studied the durability and long-run conduct of PICS boards with EPS/XPS isolated light-weight weight layer as a protective center and CFRP/GFRP shear linkers. The investigation enclosed assurance of the momentaneous extreme shear capacity of the boards, the impact of supported loads on the conduct of FRP lattice/inflexible isolated light-weight weight layer as a shear move part and also the impact of out-of-door introduction states on a definitive quality of the boards. Sections of 3-wythe boards were used instead of two-wythe boards to allow testing the FRP matrix/inflexible isolated light-weight weight layer part in direct shear and to limit the bending impacts. Underneath the sustained loading, it absolutely was expressed that for boards with GFRP matrix creep influence is restricted in distinction with CFRP frameworks if the continuing load level is restricted to a load stack balanced to a half-hour of a final capability of the GFRP lattice/inflexible isolated light-weight weight layer association. Specimens tested once exposure to the climatic zone climate of North geographic area i.e. no weather condition conditions for seven months, showed that the shear capability cut out by the twelve-tone system and 5-hitter for EPS and XPS boards severally.

Also, the decrease in flexibility was discovered. The decrease within the resistance to deformation and malleability was attributed to the aging of froth, prompting weakening of the bond. The decrease was more and more articulated for EPS foam in distinction with the XPS foam that has progressively closed cells.

2.2.1.6 For material properties: **-** The standard for material properties is different for different researchers. The experimental data used for the validation of the FEA results of the work uses the experimental guidelines of the following researchers.

(i) For slab panel, Daniel et.al (2015 and 2019) uses **ACI** and **IS 456** guidelines for cement matrix testing and analysis.

(ii) For wall panel, Gara et.al (2012) uses **EN ISO 15630-2** guidelines for cement matrix.

(iii) For shear connectors & mesh tensile strength is as per **ASTM E8 Metal Tensile Testing**.

The experimental results show the real situation behavior of the PICS boards but the shortcoming of this analysis is that either the number panels tested should be high in number to decrease the uncertainty associated with the experimental work. For that a huge investment of **M3** factor is required that is man, money, and machinery. Hence, new analytical methods are developed to decrease the cost and time associated with experimental work.

2.2.2 Analytical analysis: - This type of analysis is further divided into two parts.

(a) ANALYSIS BASED ON MATHEMATICAL STUDY

(b) ANALYSIS BASED UPON THEORY OF YIELD LINE.

Both the analysis is numerical one based upon certain assumptions. The mathematical analysis is more often performed on both slab and wall panels under their loading conditions. Whereas the theory of yield line is performed for slab boards. Both theories have their pros and cons. The theories are as follow:

2.2.1.1 Analysis based on the mathematical study: - Certain researchers have developed their mathematical model based upon their experience. They are based upon a certain parameter.

For flexure: -Tomlinson. D & Fam. (2016) A develop a model based upon certain parameters resembling the shear linker properties thickness, resistance to deformation, angle with the horizontal plane and the throughout the volume in the panel which is directly related with the spacing in a line. The code is developed in MATLAB software and the mapping to general flexural strength parameters is done by validating the results with the published results.

For punching: - Bing. L and Bing. S (2017) developed a numerical model based upon plate theory. The model inputs dimensions, material properties and value of load concentrated on a certain area. The strength outputs are got from the model which are validated with the experimental and yield line analysis. Figure 1.8 shows the deformed shape and mapping in the model.

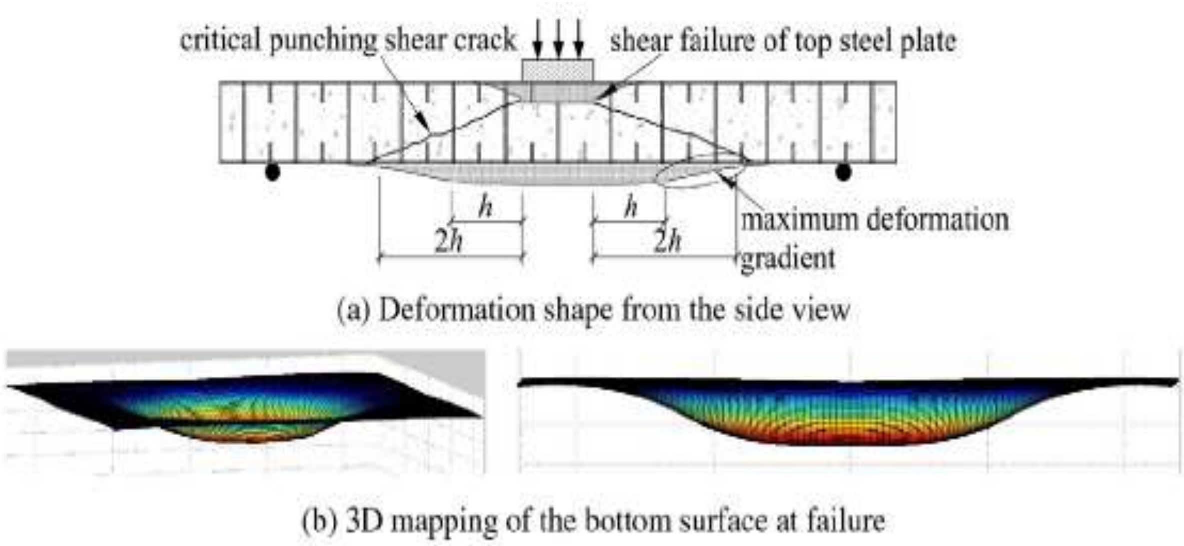


Figure 2.9: MATLAB Analysis of PICS board in punching (Bing. L and Bing. S (2017))

For wall panel: **-** Gara et.al (2012) developed a numerical model based upon the Euler ‘s theory of Buckling and find the value of maximum load taken by the panel in axial and diagonal compression. The model is validated with experimental and FEA results.

2.2.1.2 Analysis based upon the theory of yield line: - This type of analysis is done for PICS boards used as a unidirectional slab. From this analysis, the value of the collapse load is found out. This type of analysis done for boards considering no extra reinforcement. The collapse load is finding out which results in yielding of shear linkers and mesh of the board. The yield line analysis gives ultimate moment carrying capacity of the PICS boards. Daniel et.al (2015) develop a model for yield lines in flexure and punching and Bing L. & Bing S. (2017) made a yield line model in punching. Figure 1.9 shows the yield line outline for the board in punching.

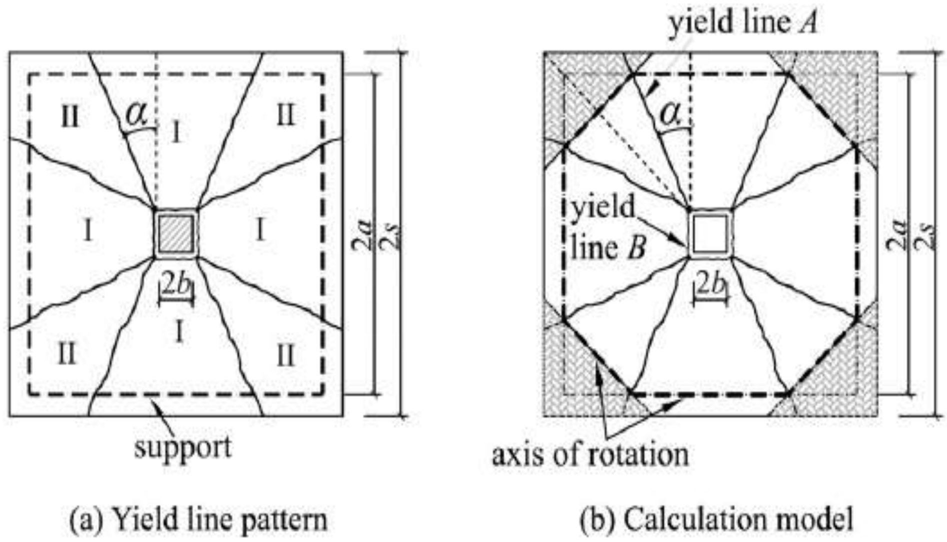


Figure 2.10: Yield line outline for PICS panel in punching (Bing L. & Bing S. (2017))

The shortcoming of the model is that it is limited to slab panels only without any extra reinforcement with unidirectional bending only which is the limited case only. Hence, the development of the FEM model takes place to overcome this difficulty.

2.2.3 FEA prototype for PICS panels: - The FEM analysis done for PICS boards is either 2D or 3D based upon the computation availability available for the analysis. The FEA analysis available till date is mostly neglecting the geometric nonlinearities of the panel, 3D structural abilities of the shear linker, crushing of concrete, properties of the isolated middle core. Hence there is a need to develop FEA model to incorporate all these abilities. The brief of various FEM prototypes available till date is as follow.

A. For slab PICS board

Benayoune et al. (2008) produce a 2 D FEA prototype with 2D mesh and shear linkers neglecting the effect of the central isolated middle core for all the possible larger dimension by small dimension ratio with materials properties in linear and Elastic region to solve the problem for flexure. The shortcoming of the prototype is that it gives the behavior to the point of elasticity which is not the real case scenario.

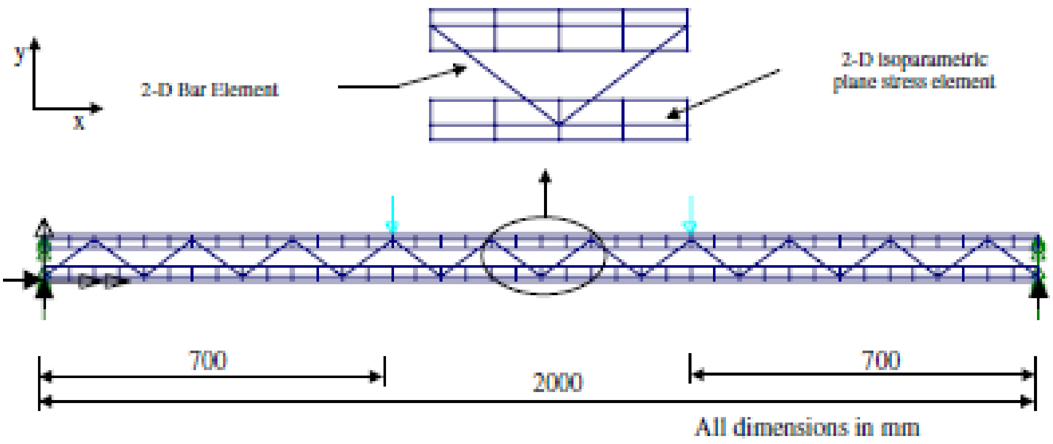


Figure 2.11: 2D FEA prototype for slab panel (Benayoune et al. (2008))

Arman Y et.al (2016) performed the same thing in FEA like Benayoune et al. (2008) with 2D concrete slab and with triangular shear linker instead of trapezoidal in flexure. The FEM prototype is validated with the experimental results produced. The shortcomings of the model are that the debonding and the slippage of the shear linker are neglected in the same linear and elastic portion. Figure 1.11 shows the FEA prototype for the analysis.

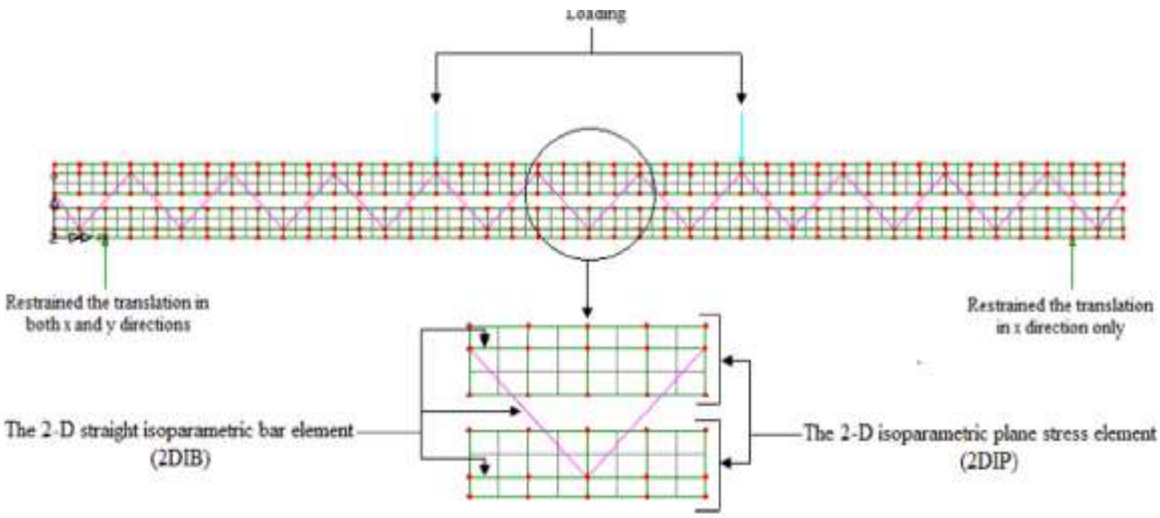


Figure 2.12: 2D FEA prototype for slab panel (Arman Y et al. (2016))

J. Daniel et.al (2018) produce an FEA prototype for slab board in both flexure and in punching. The use the ABAQUS software with 2D mesh and shear linkers but with a 3D concrete top and bottom layers. They performed the analysis with the software 's inbuilt CDP model for cement matrix. They also consider a perfect bond between the cement matrix and shear linkers and neglects debonding. Thus, the 3D effect of shear linkers is neglected. Figure 2.13 & 2.14 shows the FEA prototype for punching and flexure.

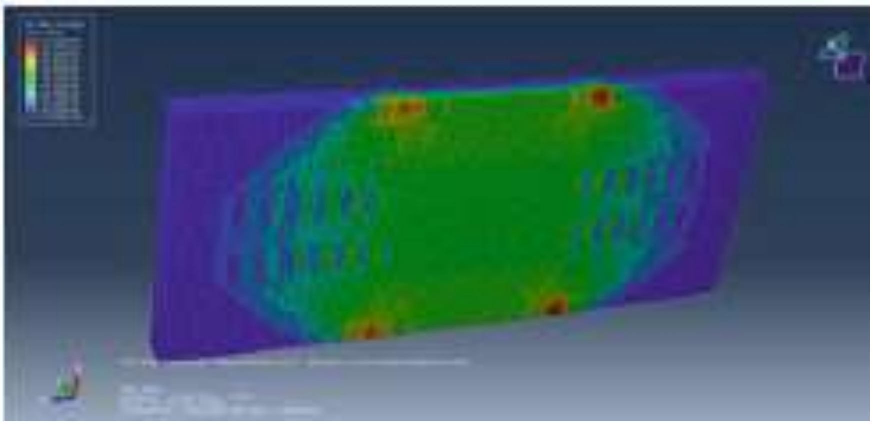


Figure 2.13: FEA results for flexure (J. Daniel et al (2018))

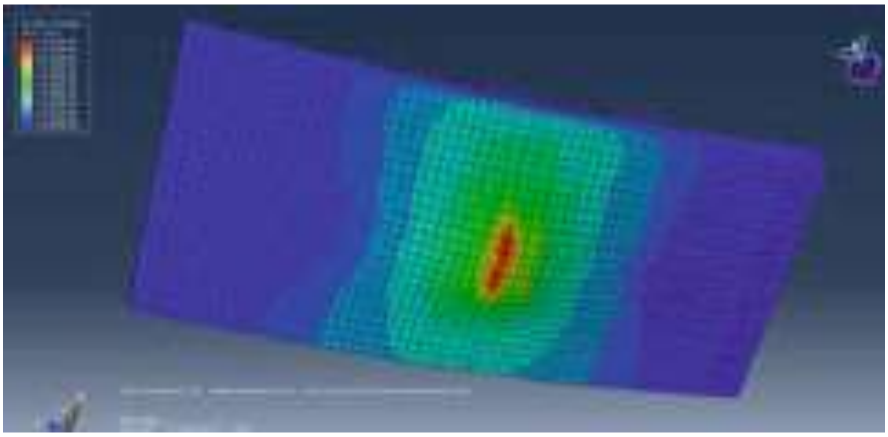


Figure 2.14: FEA results for punching (J. Daniel et al (2018))

B. FOR WALL PICS BOARD: - For wall panels, only 2D analysis is available till date. **Gara F et al (2012)** performed 2 D lineally elastic analysis of wall panel for both axial and diagonal compression. The shortcoming of the analysis is that there is a lot of difference in original work and the prototype. SAP2000 software is used for the analysis. Figure 2.15 shows the FEA prototype for it.

Arman Y et.al (2018) performed the same thing in FEA like Gara F. et al. (2012) in LUSAS 2000 software with 2D concrete wall and with triangular shear linker instead of trapezoidal in flexure. The FEM prototype is validated with the experimental results produced. The shortcomings of the model are that the debonding and the slippage of the shear linker are neglected in the same linear and elastic portion. Figure 2.16 shows the FEA prototype for the analysis.

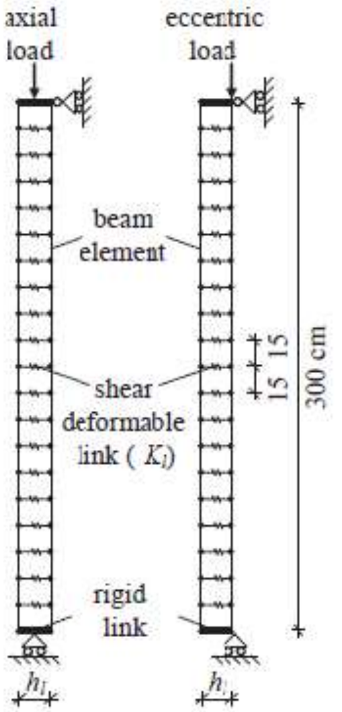


Figure 2.15: FEA prototype for wall panel (Gara F. et al (2012))

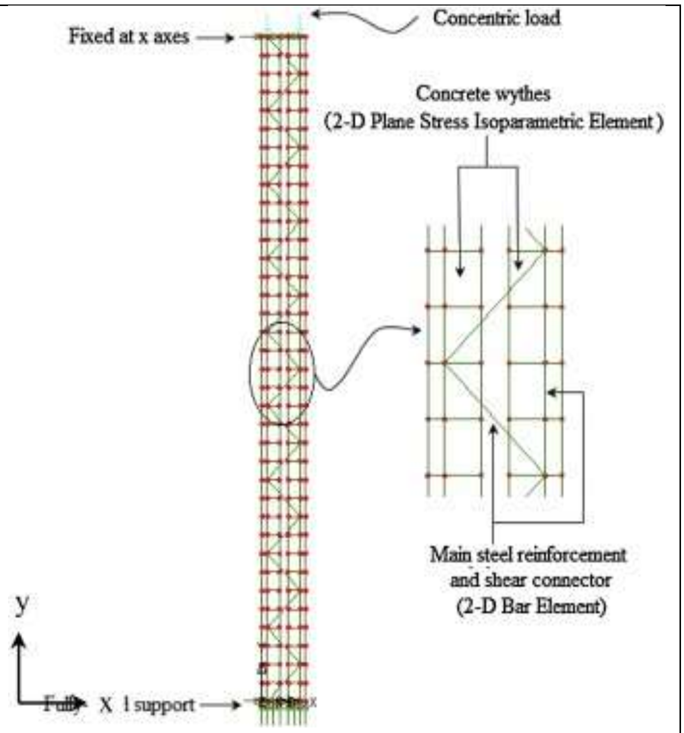


Figure 2.16: 2D FEA prototype for wall panel (Arman Y. et al (2018))

2.3 GAPS IN THE RESEARCH AREA: -

Numerous investigation studies have been done to judge the performance of PICS boards for various loading conditions. The most of the research studies performed are of experimental and numerical one or either based upon yield line theory or the FEA prototypes prepared till date are either support the 2D behavior or linear behavior of the board but no study tell us about the FEA analysis of cement matrix sandwich EPS middle sheet slab and wall boards with 3D shear linkers and this is the reason of motivation for our study.

Also, no researcher has used the ANSYS WORKBENCH software package to explore the structural behavior of the boards. ANSYS WORKBENCH software helps in the prototype the shear linkers as a 3D element. Its 3D meshing features and structural capabilities help in founding the load, displacement, moment, strain, stress and other structural parameters to accurately prototype the specimen. Moreover, the biggest advantage is to use the software both as GUI and through command coding. Hence, this gives the pathway to simulate the 3D PICS boards.

2.4 CLOSURE: -

From the literature review, it can be concluded that to make use of FEA prototype for PICS panels is indeed feasible. So, it is decided to use the ANSYS WORKBENCH 15.0 software package for the analysis of wall and slab panels made up of PICS boards. With the help of this software package, the analysis of PICS boards used as wall and slab for various relative parameters is done and at last, the validation is done with the previous literatures.

Chapter 3: FEA PROTOTYPE DETAILS OF PICS PANELS

3.1 GENERAL

This chapter explains the Finite Element approach used for the modeling of concrete sandwich EPS panels. The general-purpose software used for the analysis is ANSYS WORKBENCH 15.0. The FEA models in ANSYS WORKBENCH were made using an extension of Static Structural Simulation, that utilizes the FEA technique. ANSYS requires the material properties, geometric dimensions, support & loading conditions to solve equations for the analysis for each node and sums it for all the degrees of freedom (DOF) in each element.

The procedure for analysis for structural model is shown in figure 3.1. the primary step is requiring the materials and their physical properties. Then the production of the geometric prototype, which might be drawn in ANSYS Workbench's own integrated sketching program style prototype or the geometry is brought from the CAD files such as Solid Works. Once the geometry is complete, then the system proceeds to outlined mesh and apply forces or displacement relying upon the sort of research that's either the analysis is load controlled or displacement controlled and constraints before the solution of the prototype. Figure 3.1 shows the components of static structural analysis.

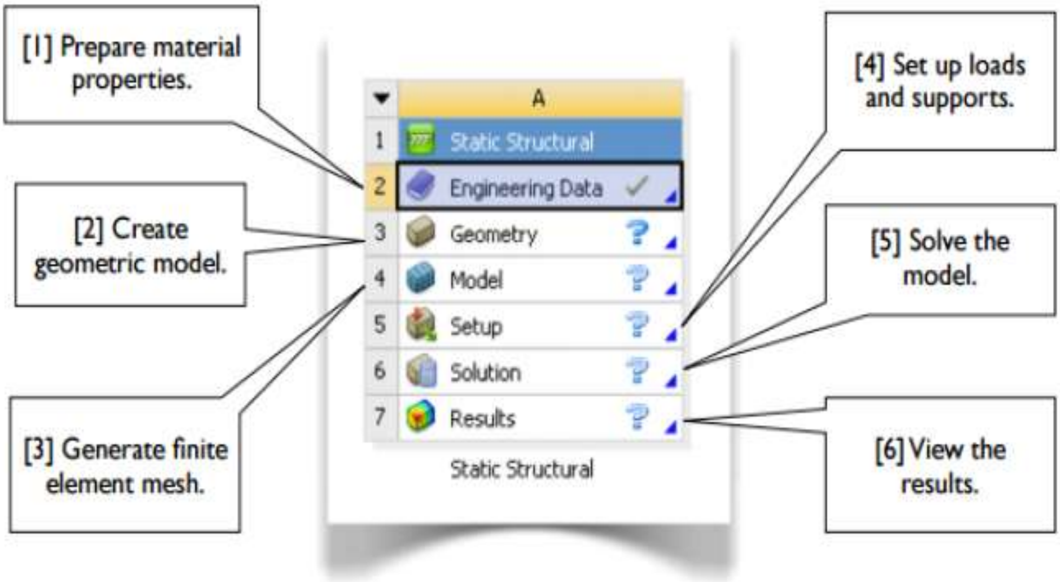


Figure 3.1: Static Structural Simulations

As proceeding further into this chapter, the whole analysis is split into two parts. The 1st part defines the prototype of Precast In-situ Concrete sandwich (PICS) slab board subjected to flexure, punching and shear sliding. The second part states the prototype of cement matrix sandwich EPS boards subjected to axial and diagonal compression but before that the assumptions made for analysis, cement matrix failure criteria, cement matrix crack prototype, and stress-strain laws for steel welded wire mesh and shear linkers are described which is common for both the analysis.

3.2 ASSUMPTIONS: -

The assumptions for FEA prototype summarized below:

- Cement matrix and Steel are a prototype as per the material standards in ANSYS.
- Steel is meant as elastic-perfectly plastic metal & indistinguishable in tension & compression.
- At the start of the analysis, strain variation is linear.
- Intact bonding exits among cement matrix and steel reinforcement.

3.3 GENERAL DESCRIPTION OF THE STRUCTURAL PANELS: -

In the experimental study carried by Gara F. et al (2012) on PICS boards with center consisting of EPS core who's top and bottom is covered by concrete skin is tested for axial and diagonal. Such panels come under the category of the wall panel. The analysis carried by Gara F. (2012) consists of three specimens tested under axial and one specimen tested under diagonal compression with no transverse shear stiffeners. Similarly, the experimental program conducted by J. Daniel et al (2019) on push off shear loading total 8 samples with varying depths and absence /Presence of central middle sheet were tested and for punching and flexure testing of PICS slab panel 1-1 sample is taken for both the test as mentioned in J. Daniel et al (2015). The testing of panels done for flexure, punching, and sliding comes under the category of slab panels.

3.3.1 Geometric and material properties of slab panels

Referring the author J. Daniel et.al (2015) one-one prototype is analyzed for punching and flexure and in J. Daniel et.al (2019) four prototype boards are analyzed for push off analysis and then the validated of the present study is done with the experimental one. The dimension structured of the boards are shown in figure 3.2 and 3.3 for flexure and punching respectively and table 3.1 gives the dimensions for the specimen used under push-off test as per the author. For push-off test inclined shear linkers are used with 70^0 inclination. The thickness of shear linkers, as well as welded wire mesh, is 3 mm for all the cases. The size of the welded wire mesh is 100 x 100 mm for the push-off test.

The material properties are encapsulating in Table 3.2 for the PICS composite. For the steel welded wire mesh and the truss shape shear linkers, Young's modulus of elasticity is $E_s = 2 \text{ X } 10^5$ MPa and maximum tensile strength got by the author as σ_T= 650 MPa. Conferring to Fanning, when the concrete is in linear isotropic range, the compressive resistance offered to deformation found from the experimental assessment of cement matrix cube as 45 MPa, and the value of young modulus of elasticity as 33540 MPa. The value of E_c comes from equation 1

$$Ec = 5000\sqrt{Fck} = 5000\sqrt{45} = 33540 \text{ MPa} \quad \ldots\ldots\ldots (3.1)$$

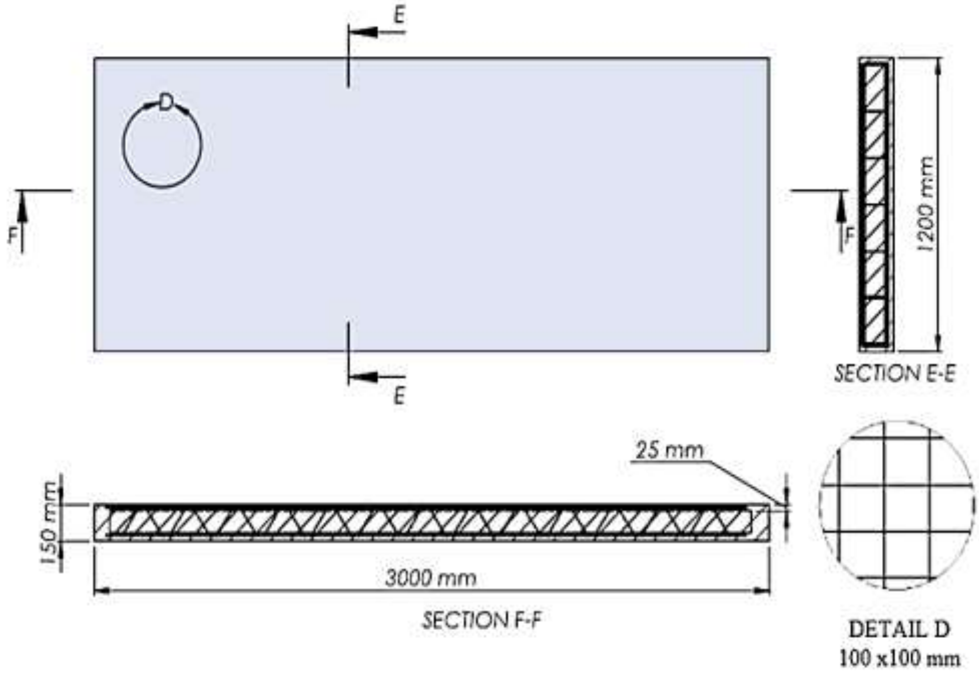


Figure 3.2: Representation sketch of PICS board under flexure

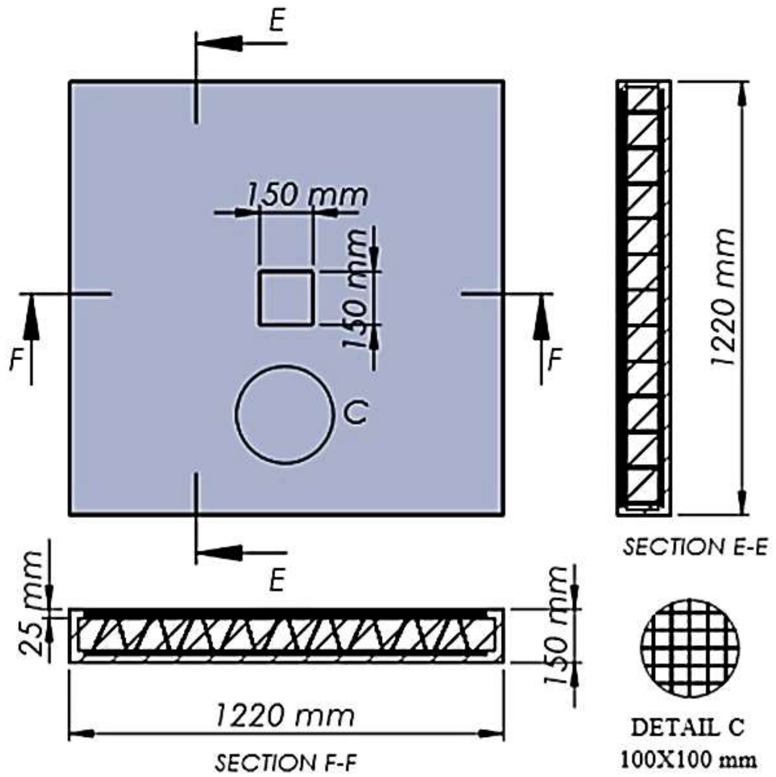


Figure 3.3: Representation sketch of PICS board under Punching.

Table 3.1: Dimensions of PICS specimens in PUSH OFF analysis.

S. No	modal name	Measurements	Depth of EPS middle sheet	The total depth of the sample
		(l x d)	(C)	(t)
		(mm x mm)	(mm)	(mm)
1	FEM-A	475x600	100	150
2	FEM-B	475x600	50	100
3	FEM-C	475x600	no middle sheet	150
4	FEM-D	475x600	no middle sheet	100

Table-3.2 Properties of materials for slab panel

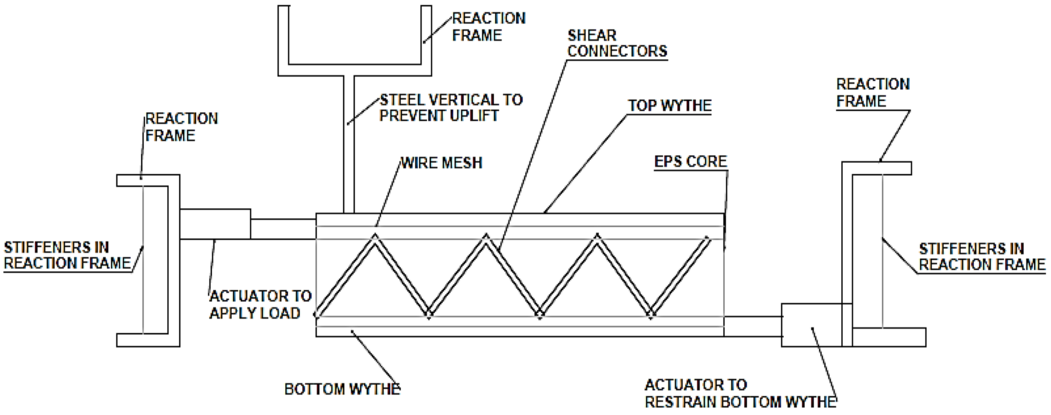
Properties of material for analysis of slab panel				
S. No	Property	Cement matrix	EPS	steel
1	Density	2400kg/m^3	16 kg/m^3	7850 kg/m^3
2	Modulus of elasticity (Es)	33540 MPa	5 MPa	200000 MPa
3	Poisson's ratio(μ)	0.18	0.25	0.3
4	Tensile Resistance to deformation	4.35 MPa	0.01 MPa	650 MPa
5	Compressive Resistance to deformation (f_{ck})	45 MPa	2 MPa	450 MPa

3.3.2 Boundary conditions: -

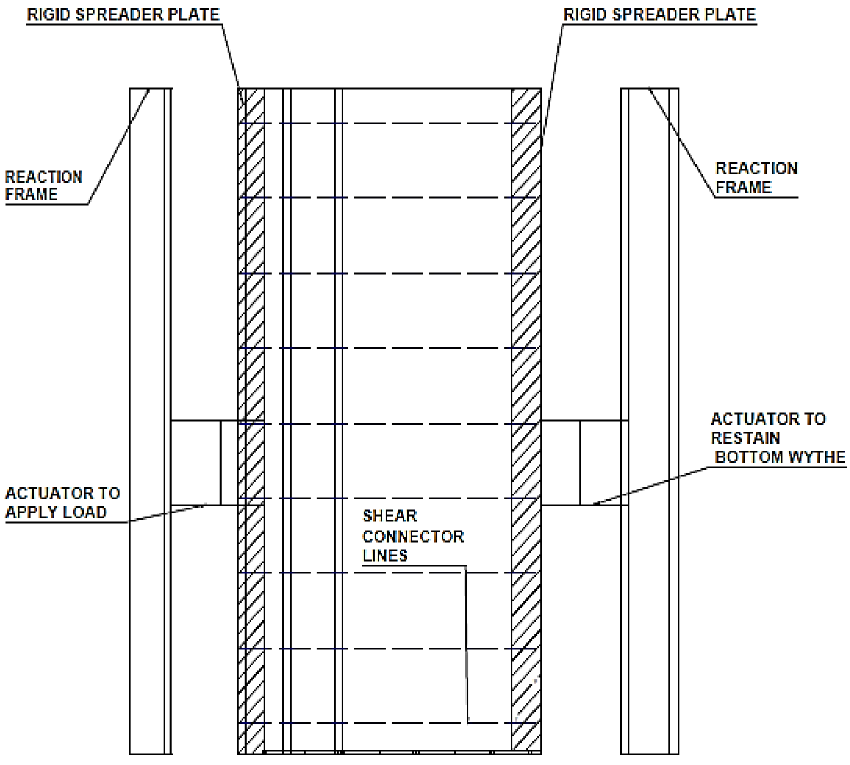
The analysis of PICS boards is done as per the experimental tests implemented by J. Daniel et.al (2015 & 2019) in his research papers. For push-off analysis, the shear loading on slab board in a lateral direction is applied at the top wythe of the slab while taking the bottom face as fixed support under boundary condition and the comparative displacement is measured with respect to the bottom wythe in figure 3.4.

In punching and four-point bending one boundary condition is applied as a roller and the other one is a hinge. The forced conditions are as per figure 3.5 and 3.6 which matches with the reference paper of J. Daniel et.al (2015).

For FEA prototype the boundary conditions are shown in figure 3.4 to 3.6. Since the analysis is done implicitly therefore for generating these boundary conditions Face split command is used which divide the face into the required number of parts so that an extra edge is created which is used for developing the boundary conditions



(a) Elevation



(b) Plan

Figure. 3.4. Illustrative diagram of Push off test setup.

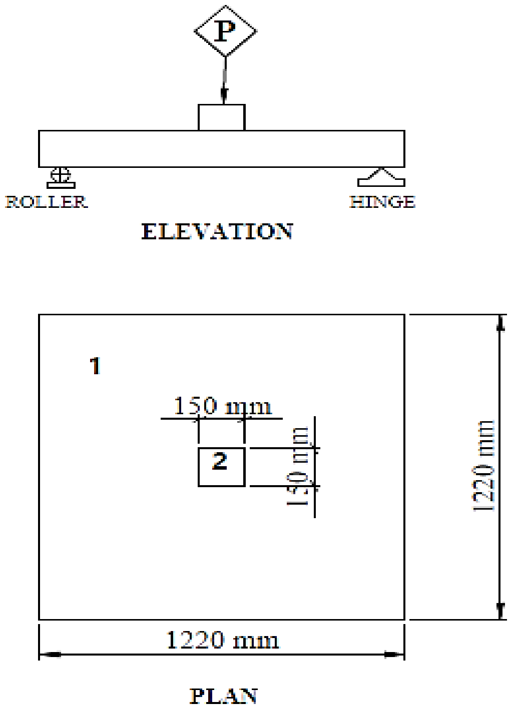


Figure 3.5 FEM structure for analysis in illustrative view punching force test

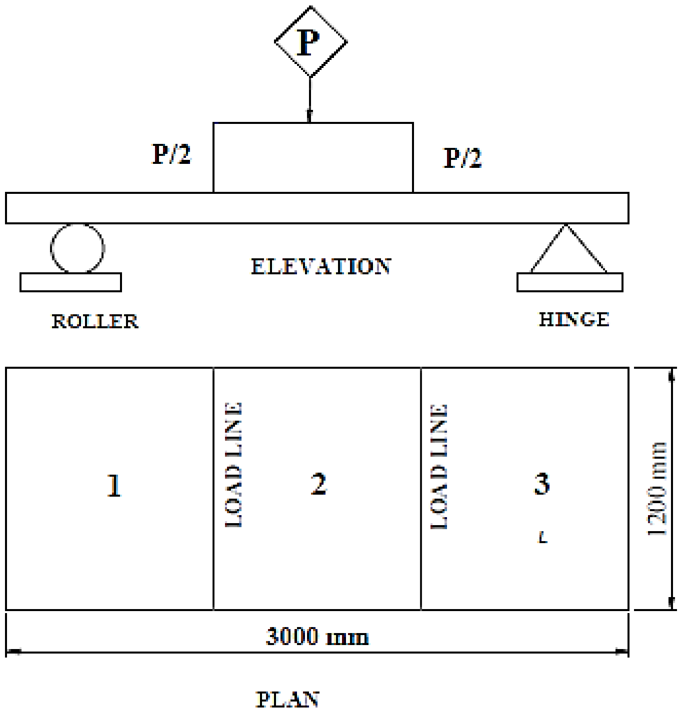


Figure.3.6 FEM structure for analysis in illustrative view four-point bending force test

3.3.3 Geometric and material properties of wall panels

Referring the author Gara F et.al (2012) the dimension details of the boards are shown in figure 3.7 and 3.8 for axial and diagonal compression respectively and table 3.3 gives the dimensions for the specimen used under axial and diagonal compression as per the author. The shear linkers are used for axial and diagonal compression are 90^0 perpendicular shear linkers. The thickness of shear linkers, as well as welded wire mesh, is 3 mm. The size of the welded wire mesh is 75 x 80 mm for axial and diagonal compression. The thickness of cement matrix wythe used is 35 mm for both top and bottom wythe in axial and diagonal compression analysis. Table 3.4 consolidates the material properties for all material components. For steel wire and truss shear linkers the experimental test gives maximum tensile resistance offered to deformation as σ_T= 650 MPa and the Young modulus of elasticity E = 2 X 10^5 MPa. Conferring to Fanning, the young modulus of elasticity is 10500MPa and the cement matrix cube compressive resistance to deformation taken from the experimental test as 20 MPa. The value of E_c comes the reference paper.

Table 3.3: Structural dimensions of PICS wall specimens

S. No	**Model name**	**Depth of EPS middle sheet**	**Total Depth of sample**	**Slenderness ratio**	**Testing condition (compression)**
		(C) (mm)	(t) (mm)	**(λ)**	
1	FEM-E	80	150	20	axial
2	FEM-F	120	190	15.78	axial
3	FEM-G	160	230	13.04	axial
4	FEM-H	80	150	8	diagonal

Table-3.4 Properties of materials used for making PICS wall panels

Properties of material in Axial and Diagonal compression				
S.No	Property	Cement matrix	EPS	steel
1	Density	2300kg/m^3	16 kg/m^3	7850 kg/m^3
2	Modulus of elasticity (Es)	10500 MPa	5 MPa	200000 MPa
3	Poisson's ratio(μ)	0.2	0.25	0.3
4	Tensile Resistance to deformation	2.34 MPa	0.01 MPa	650 MPa
5	Compressive Resistance to deformation (Fck)	20 MPa	2 MPa	450 MPa

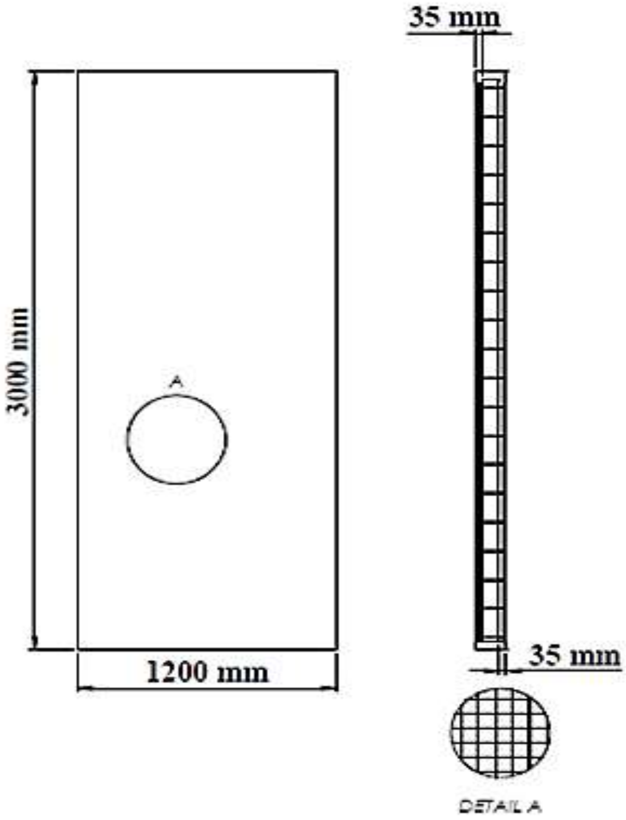


Figure 3.7: Illustrative sketch of PICS board used of axial compression

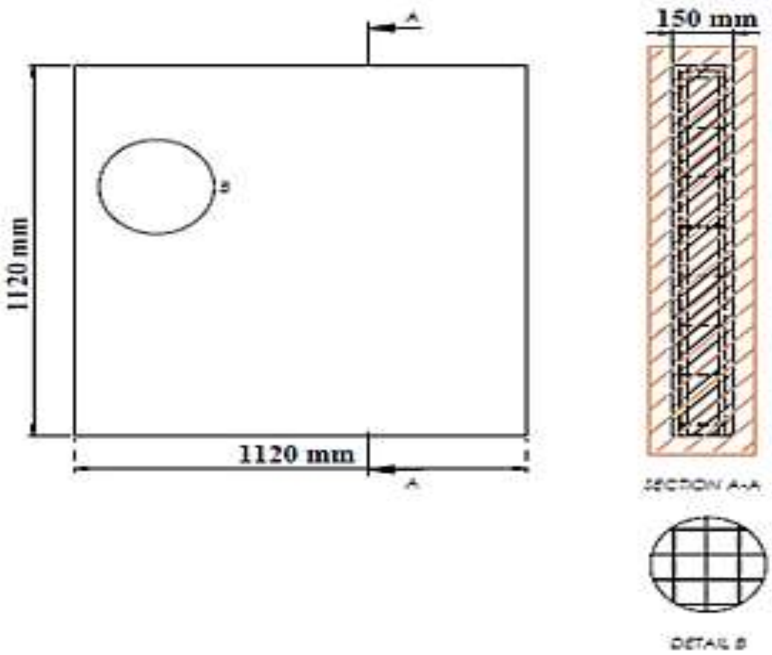


Figure 3.8: Illustrative sketch of PICS board used of diagonal compression

3.3.4 Boundary conditions: -The analysis of PICS boards is done as per the experimental assessments are done by Gara et.al (2015) in the reference papers. For axial compression bottom plane and the top edge is kept fix and load is applied from the top edge. For the diagonal corner of the to adjacent sides is fixed and load is applied from the opposite corner. Figure 3.9 and 3.10 shows the boundary conditions for the wall panel.

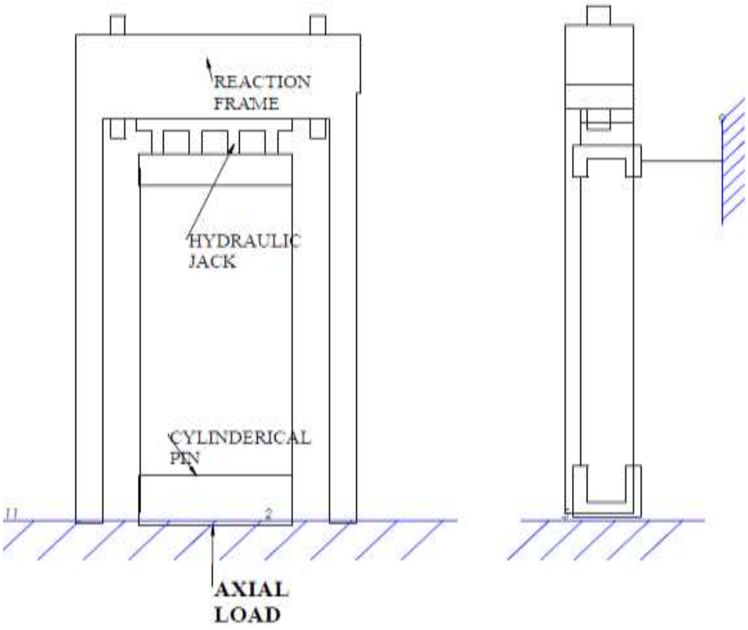


Figure 3.9 FEA illustrative view structured for axial force set up

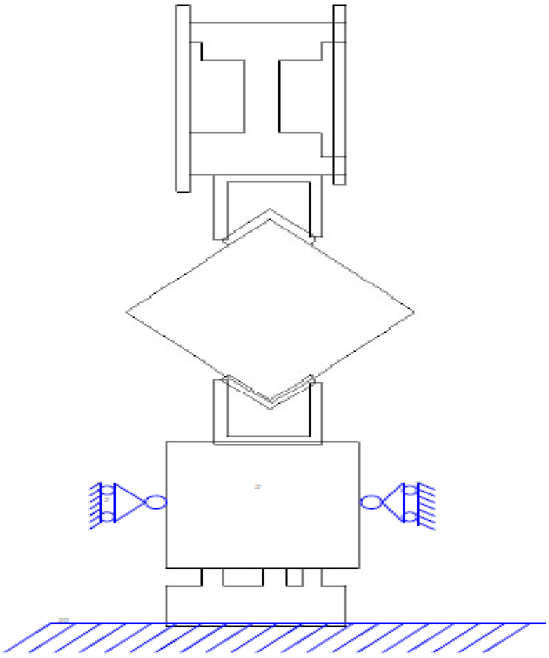


Figure 3.10 FEA illustrative view structured for diagonal compression

3.4 INTRODUCTION TO FINITE ELEMENT MODELLING: -

With the progress of engineering and computational power for analysis, the trend of developing new methods to solve the real-world problem through mathematical evaluation is also increasing. One of such new methods is the analysis through the FEM model. The FEM analysis is pretty handy now these days and trending due to its effectiveness in solving the models.

3.4.1 Finite Element Method

FEM is a computer-based numerical procedure to solve the boundary value problem, integral and partial differential equation approximately. The differential equation is solved either fully or by converting the differential equation into ordinary form and finding the solution through some numerical integration technique.

The FEA analysis consists of the following steps.

(i) Discretization (meshing) the deformable body since the discretization of the rigid body does not matter in the analysis.
(ii) Interpolation function selection.
(iii) Providing material properties.
(iv) Accumulating the properties of material into the differential equation.
(v) Granting the boundary condition associated with the analysis.
(vi) Solving the problem.
(vii) Making extra computations if required.

3.4.2 FEM Analysis applications

(i) It gives the visual description of the required load or displacement analysis.
(ii) Capable of handling complex geometry and loading.
(iii) The analysis saves a lot of time and cost associated with the experimental analysis.
(iv) Easy to construct, redesign, redefine and optimization of the problem according to requirement and analysis.
(v) No problem of pollution by carbon footprint of cement which is associated with the experimental testing because in concrete testing the use of cement is made and the waste created after the experimental testing causes a problem of dispose off.

3.5 FINITE ELEMENT MODELLING: -

The FEA technique is a mathematical computer-based structural component analysis method in which the response of each element is recorded in terms of its degree of freedom as a value of shape function. FEA is well suited for complex systems having irregular geometry. The tools of ANSYS WORKBENCH software are capable enough in performing the nonlinear analysis for various structural components. The inbuilt material models for concrete, steel, and other engineering materials helps in performing accurate analysis for the structural components and real-time performance of the structure. The working environment of the ANSYS software and the GUI (graphical user interface) is very user-friendly but it requires more memory space on the computer. The minimum RAM required for the analysis is 4 GB and a hard disk of 500 GB. But with this memory space, only the processing of the software is very slow. Hence, it is required to use high memory space computer for accurate analysis.

3.6 MATERIAL MODEL: -

The software package offers various inbuilt material models for various engineering materials. The most useful prototype for the analysis of EPS concrete sandwich panels are concrete (cement matrix), steel for shear linkers and welded wire mesh and of Expanded polystyrene (EPS) for the middle isolated core. The details of the models are as follows.

3.6.1 Cement matrix prototype in Ansys workbench: -

1) Geometry of concrete

Any 3d brick element with 8 to 20 nodes is used for the analysis of concrete. Figure 3.11 shows the 3 D brick element.

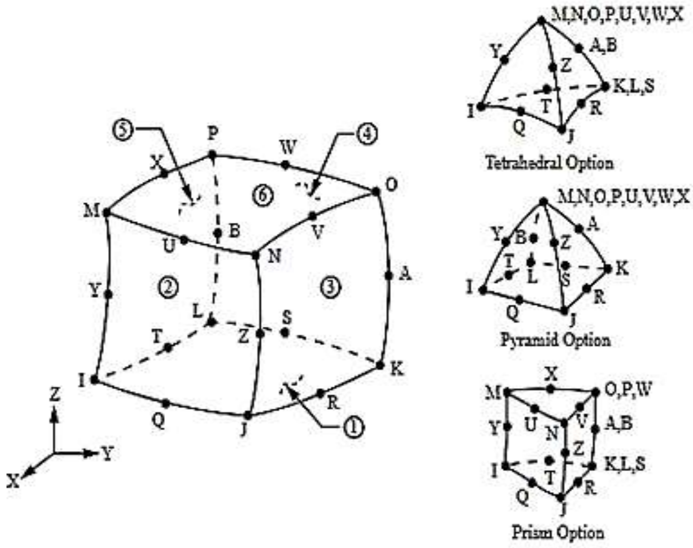


Figure 3.11: 20 nodded brick elements. (SAS 2013)

2) Elemental properties

SOLID186 is used for the modeling of concrete. It is a 3-D FEM analysis brick element. It is a higher order element. It's a solid brick element with 20-nodes of which 8 nodes are at the edge joints and 12 nodes are at the middle of the 12 edges of the brick. SOLID 186 exhibits quadratic displacement behavior is used to prototype cement matrix and EPS middle sheet. The element has 3 degrees of freedom (DOF) at each node. The element also has translations in all x, y, and z nodal directions. The element is able to perform cracking in 3 orthogonal directions, plastic deformation, and crushing.

3.6.2 Shear linker and welded steel wire mesh prototype in ANSYS WORKBENCH: -

1) The geometry of steel linkers and mesh

The modelling of shear linkers and mesh can be done either discrete or in smeared fashion. In the present work smeared modelling is used. The modelling is done in both ways i.e. like 2D truss element or 3D tetrahedron element. In the present study, 3D tetrahedron element is used. Figure 3.12 shows the 3 D tetrahedron element for steel.

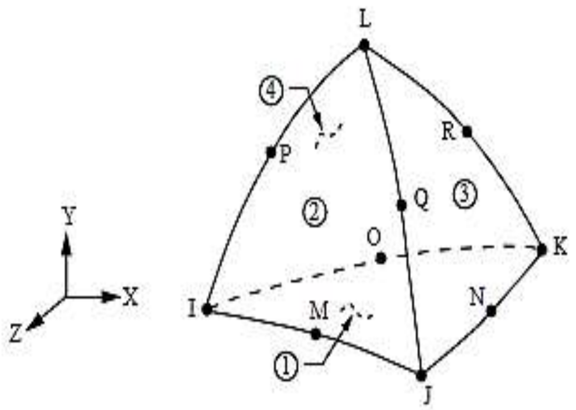


Figure 3.12: 3D tetrahedron element (SAS 2013)

2) Elemental properties

SOLID187 is used for modeling of the shear linker and welded wire mesh. The element has advanced properties to prototype irregular meshes (such as those produced from various CAD/CAM systems). It is a 3-D higher order element. It has 10-nodes. This element is carried to prototype steel wire mesh and truss type shear linkers. This element has a quadratic displacement behavior. The element having 3 DOF at respective node and translations in the x, y, and z nodal directions.

3.6.3 EPS sheet prototype in ANSYS WORKBENCH

Since these sheets are lightweight material comprises of very low strength. Hence, its detail modeling is not as crucial as of steel and concrete. So, a linear behavior of these sheets is considered with solid 186 elements for its modeling.

3.6.4 Other important modelling elements: -

Besides the above-discussed elements some other elements are used for the bonding and the nonlinear behaviour they are as follow:

SURF154 is a 3-D structural element used for numerous load and plane impact functions during analyses. Face split command is used to split the face into two and 3 parts to apply load onto the body. CONTA173 and TARGE170 are the elements used to characterize the interaction between the welded wire mesh, truss shear linkers and cement matrix interface. These elements have a capability to simulate the presence of force between them when there is interaction, and separation between them when there is not. Figure 3.13 shows the pictorial view of these elements.

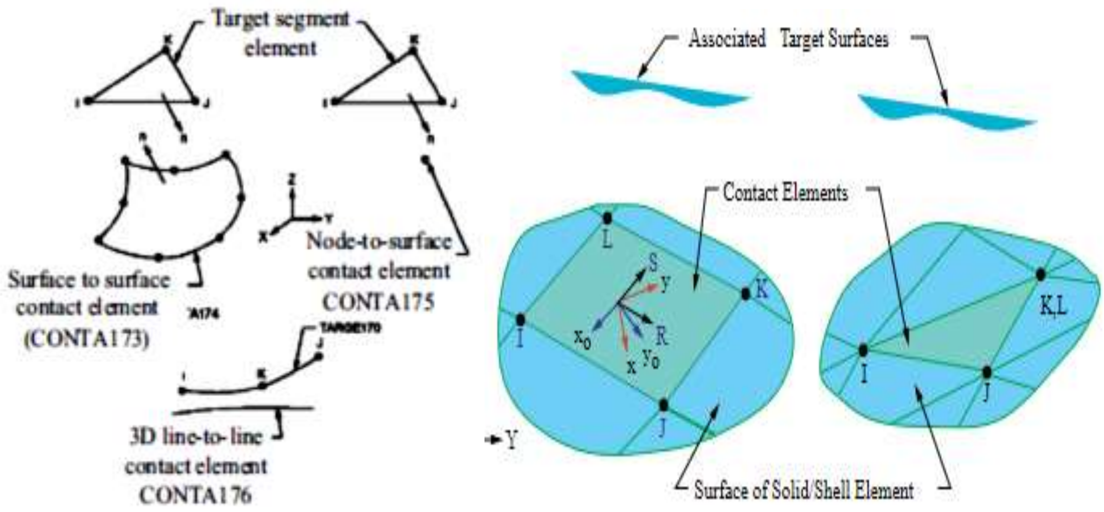


Figure 3.13 TARGE170 and CONTA173 Geometry. SAS (2013)

3.7 CEMENT MATRIX (CONCRETE) FAILURE STANDARDS: -

The FEA behavior of the material highly depends upon the mathematical equations chosen for the analysis and the values of parameters input into the model of finding the solution. Hence, choosing a failure standard is the primary phase to observe cement matrix behavior. The failure progression of cement matrix is complicated since concrete is heterogeneous material although it is considered to be homogeneous for the analysis. The force distribution in concrete is possible due to the grain to grain or particle to particle force transfer. Also, there is the formation of the interfacial transition zone (ITZ) at the cement and aggregate interface which leads to the softening of the concrete after certain stress-strain limit. There the choice of concrete failure model is thus become very important to visualize the real environment behavior. There are numerous failure standards are existing, from the analysis like straightforward maximum tensile stress standard and maximum tensile strain standard with only one constraint to the Mohr-Coulomb and Drucker-Prager standards with two constraints, and Willam-Warnke criteria with 3 or 5 constraints. With extra constraints, precision is improved but the complexity is also amplified unavoidably. Willam and Warnke (1974) established broadly admired prototype of triaxial failure plane of unconfined ordinary cement matrix. The plane in failure in principal σ-space is shown in Figure 3.14. Prototypes ponder a sextant of the principal space for the reason that the components are structured according to $\boldsymbol{\sigma_1 \geq \sigma_2 \geq \sigma_3}$**.** These σ components are the major principal stress.

The failure plane is divided into two segments as deviatoric (transformation in shape) and hydrostatic (transformation in volume) in Figure 3.15. The hydrostatic segment formulae meridional plane comprises the equisectrix $\boldsymbol{\sigma_1 = \sigma_2 = \sigma_3}$**.** as an axis of rotation (see Figure 3.14). The deviatoric segment shown in Figure 3.15 rests in a plane normal to the equisectrix (dots marked in Figure 3.15).

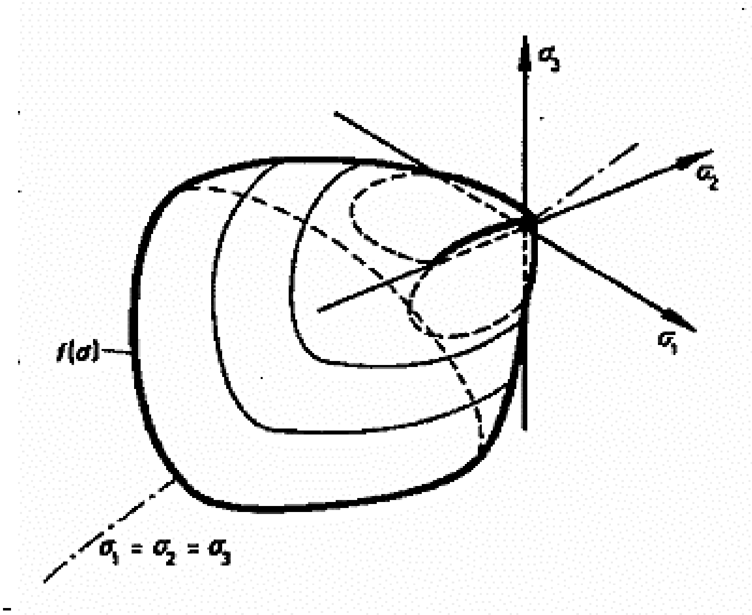


Figure 3.14 –Triaxial state for Failure Plane of ordinary Cement matrix (Willam and Warnke 1974) (Razaghi et at. (2005))

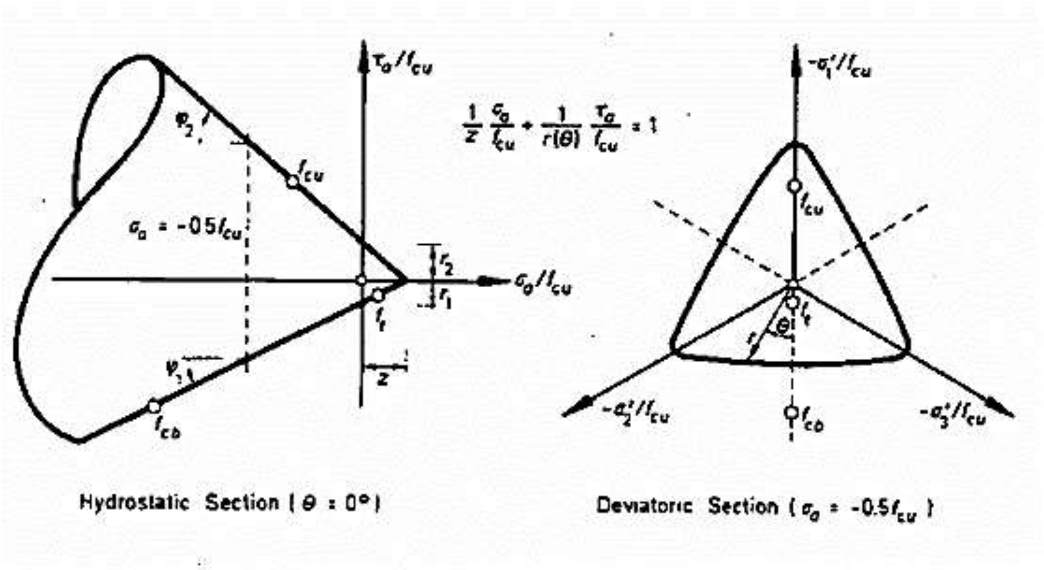


Figure 3.15 – 3 Constraint Prototype (William and Warnke 1974) (Razaghi et at. (2005))

The deviatoric trace is defined by polar coordinates *θ* and *r,* where angle, *θ* is the angle of failure plane located by position vector *r*. The failure plane is described as:

$$\frac{1}{z}\frac{\sigma_a}{F_{cu}} + \frac{1}{r(\theta)}\frac{\zeta_a}{f_{cu}} = 1 \qquad (3.1)$$

here: σ_a & ζ_a = mean stress vectors,

Z = plane summit

F_{CU}= uniaxial compression resistance to deformation.

The hydrostatic cone is opened by the role of two angles φ_1 and φ_2. The free constraints of the failure plane *Z* and *r*, are recognized by the uniaxial compression resistance to deformation (f_{cu}), biaxial compression resistance to deformation (f_{cb}), and uniaxial tension resistance to deformation (f_t).

Established on overhead standards, a built-in cement matrix prototype for the appropriate FEA employment was framed. This built-in prototype for cement matrix presumes a suitable account for the material failure. The yield state is approximated by 3 or 5 constraint prototypes classifying elastic from inelastic deformations and linear from non-linear using the failure envelope stated by a scalar function of σ $f(\sigma)=0$ as a result of flow rule while using growing stress-ε relations. The constraints for the failure plane can be observed in figure 3.3

Throughout switching from elastic to brittle or elastic to plastic behavior, 2 mathematical policies were suggested: proportional penetration, which splits proportional loading into an elastic and inelastic sections which control the failure plane by means of integration and the second one is normal penetration, which permits the elastic track to reach the yield plane at the intersection with the normal thus evaluating a linear system of equations. Both of these procedures are possible and gives stress values that fit the constitutive constraint state.

3.8 WILLIAM AND WARNKE MATERIAL PROTOTYPE FOR CONCRETE: -

The William and Warnke (1975) (Razaghi et at. (2005)) prototype is able of forecasting cement matrix material failure. All together crushing and cracking failure modes are considered. The value of two resistance to deformation constraints entered into the prototype– i.e. compression resistance to deformations (**f_{ck}) and** ultimate uniaxial tensile – that required to describe a failure plane of concrete. Subsequently, state for the failure of cement matrix can be calculated by multiaxial stress state (William and Warnke, 1975) (Razaghi et at. (2005)). Figure 3.16 shows a 3-dimensional failure plane for cement matrix.

The utmost noteworthy thing is non-zero value principal stress are within the X and Y directions severally. The three failure planes in for the value different stress components in the direction of the stress plane are shown in figure 3.16 which displayed the predictions of stress on the σ_{xp} - σ_{yp} principle stress plane. The mode of failure is dependent on the sign of σ_{zp} (value of principal stress in the Z direction). As an illustration, if σ_{xp} & σ_{yp}, each is negative (compression) and σ_{zp} is slightly positive (tensile), cracking would be foreseen in a very direction perpendicular to σ_{zp}. However, if σ_{zp} is zero or slightly negative, the fabric is taken into account as crushed. Implementation of the William and Warnke material prototype in Ansys 15.0 needs different constants values based upon the material properties.

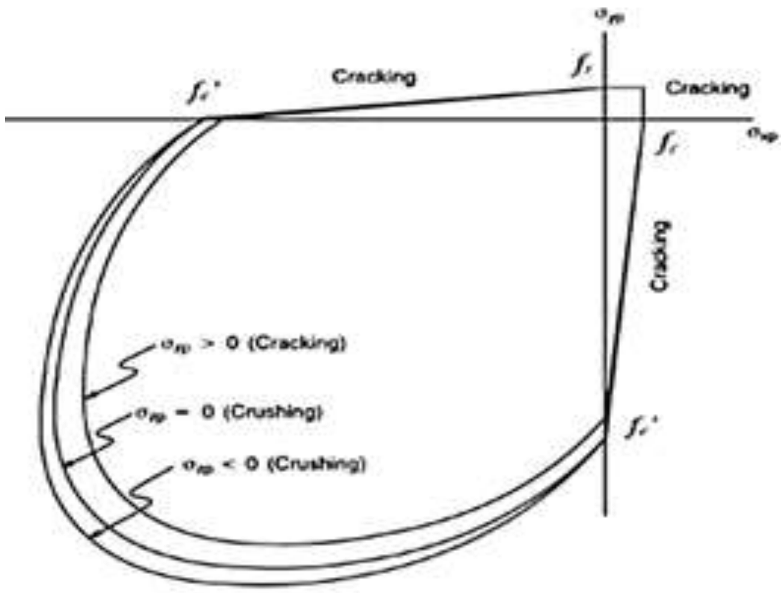


Figure 3.16: Cement matrix Failure plane (Razaghi et at. (2005))

3.9 BEHAVIOUR AND MODELLING OF CRACKED CONCRETE: -

The procedure of crack progression is often separated into 3 phases as shown in Figure 3.17. In a cement matrix part, cracking happens once the principal tensile σ in any direction lies outside the failure plane. When in cracking, the coefficient of elasticity of the cement matrix part is prepared to zero within the direction parallel to the principal tensile stress direction. Crushing happens once all principal stress is compression and lie outside the failure plane; after, the coefficient of elasticity is ready to zero all told directions (SAS, 2013), and therefore the part effectively disappears. throughout this study, it absolutely was found that if the crushing capability of the cement matrix is turned on, the finite part beam prototypes fail untimely. Crushing of the cement matrix began to develop in components set directly underneath the masses. after, adjacent cement matrix components crushed among many loads step further, considerably reducing the native strength. To overcome this abnormality 20 nodded brick element should be used to account crushing failure. 2 mainly completely unlike methods are utilized for the crack prototype. These are (a) discrete crack prototype (b) smeared crack prototype. The 1st tactic is suffering from few drawbacks, because it physically engaging however in this method employment of a continual amendment in nodal property is done, that doesn't slot in the character of finite part displacement method; the crack is taken into account to follow a predefined path on the part edges and excessive process efforts are needed. The 2nd method is that the smeared crack method. during this method, the cracks are assumed to be smeared get in a continual manner.

Within the smeared conception 2 choices are accessible to prototype a crack: the fixed crack prototype and therefore the rotating crack prototype. In each prototype, the cracking occurs when principal stress outdoes the resistance to deformation. it's presumed the uniformity in distribution of the cracks are at intervals the volume fabric. Those can be mirrored within the constitutional prototype by an introduction of orthotropy.

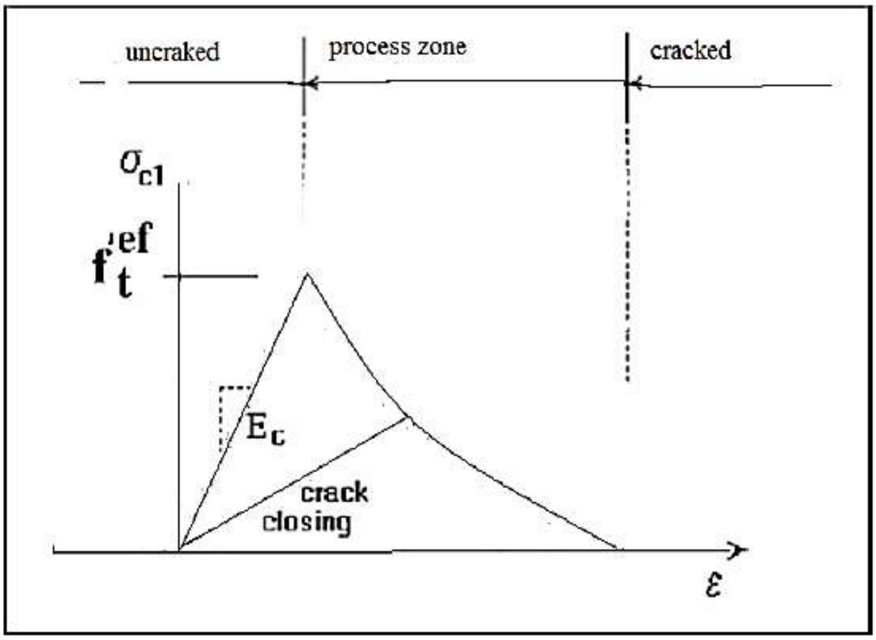


Figure 3.17 Phases of the opening of a crack in cement matrix in FEA (SAS 2013)

3.10 PROTOTYPE COEFFICIENTS OF CONCRETE: -

Material Prototype for cement matrix states to element Solid186. Solid186 for properly prototype of cement matrix in FEA prototype needs linear isotropic and multilinear isotropic material properties. For multilinear isotropic material, the von-Mises failure standard is frequently used in ANSYS in addition to the Willam and Warnke (1974) prototype to describe the cement matrix failure.

$$E_c = 5000\sqrt{f_{ck}} \qquad (3.2)$$

As suggested by past researchers for the cement matrix prototype the compression uniaxial stress-ε relationship was obtained using the following equations for the prototype.

$$f_{ck} = \frac{Ec}{1+\frac{\varepsilon}{\varepsilon_0}} \qquad (3.3)$$

$$\varepsilon_0 = \frac{2f'_c}{E_c} \qquad (3.4)$$

$$E_c = \frac{f}{\varepsilon} \qquad (3.5)$$

where: f = stress at any strain ε, MPa

ε = strain at stress f_{ck}

ε_0= strain at the ultimate compression resistance to deformation f'_c

The multilinear isotropic σ-ε implemented needs the primary point of the curve to be termed by the analysis. Its necessity condition is to fulfill the proportionality limit i.e. Hooke's Law;

$$E = \frac{\sigma}{\epsilon} \qquad (3.6)$$

The multilinear curve is used to help with the convergence of the Nonlinear solution algorithm. From the above equations, the value of σ vs ε comes out. For the execution of the Willam and Warnke (1975) prototype in ANSYS WORKBENCH 15.0, there is a requirement of 9 constants (**SAS, 2012**). Those 9 constants used during the analysis of wall and slab are given below.

Table 3.5- Values of coefficients used for analysis

S. no	Coefficient	value
1	open crack Shear transfer coefficient	0.5
2	Closed crack Shear transfer coefficient	1
3	Tensile cracking σ in a uniaxial direction	4.5 MPa -slab panel and 2.4 MPa- wall panel
4	Crushing σ in a uniaxial direction	45 MPa -slab panel and 20 MPa- wall panel
5	Crushing σ for biaxial direction.	0
6	Ambiance hydrostatic	0
7	Value of ambiance hydrostatic σ state for Biaxial crushing σ.	0
8	Value of ambient hydrostatic σ state for Uniaxial crushing σ.	0
9	Value of Strength multiplier under the cracked tensile state.	0

1. As presented by Razaghi et at. (2005) open crack Shear transfer coefficient recommended range is from 0.2 to 0.5. Value of open crack Shear transfer coefficient was entered as 0.5.
2. As presented by Razaghi et at. (2005) Closed crack Shear transfer coefficient suggested array is from 0.0 (for on behalf of a smooth crack, i.e., complete loss of shear transfer), to 1 (for on behalf of a rough crack, i.e., no loss of shear transfer). Value of Closed crack Shear transfer coefficient was input as 1.
3. The value of Tensile cracking σ in uniaxial direction was based upon the modulus of rupture and was entered as 0.1 f_{ck} that is 4.5 MPa.

4. The value of Crushing stress (σ) in uniaxial direction was based on the uniaxial unconfined compression resistance to deformation and was entered as 45 MPa, to turn ON the crushing ability of the cement matrix component as discussed by Kachlakev and Miller (2001).
5. The value of factors from 5 to 9 was employed as 0, as conferred by Wolanski and B. (2004), in order to encounter the ANSYS convergence problem.

3.11 STRESS-STRAIN (σ-ε) LAWS FOR STEEL SHEAR LINKERS: -

In the present problem, the shear linkers are a prototype as 3-D truss elements. So, for that reason tetrahedron type meshing is done with 10 nodded tetrahedron element. The contact among the cement matrix and Steel is bonded. For the prototype of shear linkers, the form of uniaxial σ is presumed and the same preparation of σ-ε law is used in all shear the shear linkers.

3.11.1 Bilinear law: -

The bilinear law, elastic-perfectly plastic, is presumed as displayed in Figure 3.9. The initial elastic segment has Young's modulus of elastic of Steel Es. The 2nd segment characterizes the Steel plasticity with hardening of Steel and hardening modulus E_{sh} is shown by its slope. For the perfect plastic case, the value of modulus is E_{sh} =0. Limit strain $\boldsymbol{\varepsilon}_L$ represents limited ductility of Steel.

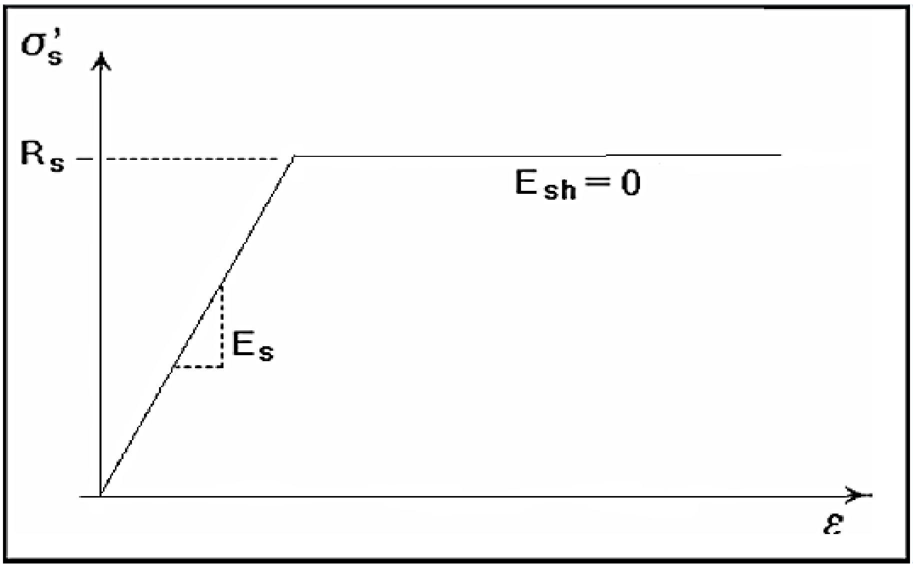


Figure 3.18 The bilinear σ-€ rule for steel (SAS 2013)

3.11.2 Multi-linear law: -The multi-linear law consists of more than two shapes as shown in Figure 3.7. This rule lets to the prototype of all phases of Steel conduct: elastic state, yield plateau, hardening and fracture. The multiline is definite by σ ε values, which can be structured by input.

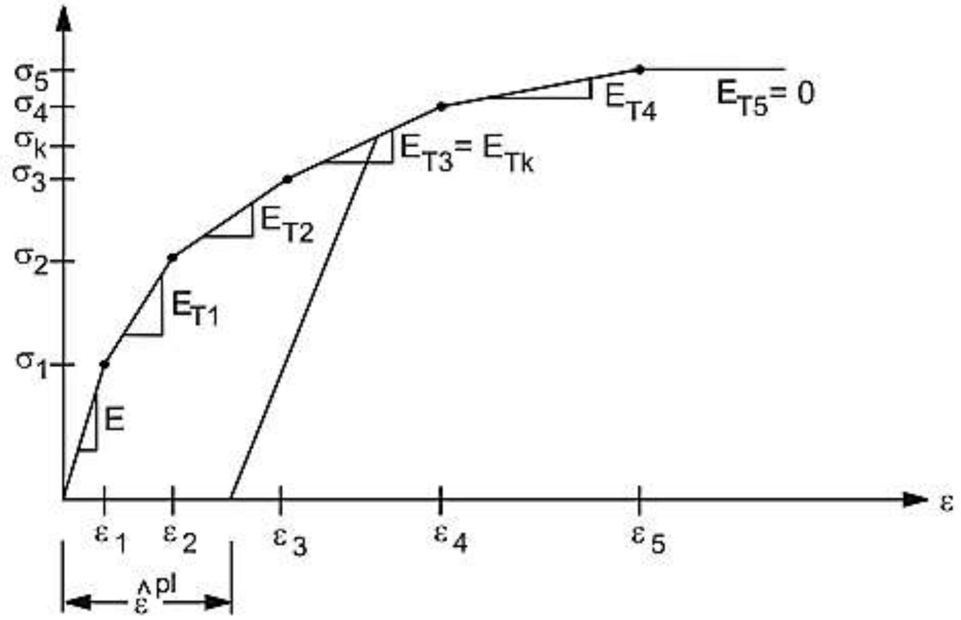


Figure 3.19 The multi-linear σ-€ law for Steel (SAS 2013)

3.12 PROCEDURE FOR FEA MODELLING OF PICS PANELS: -

Mainly the FEA modeling of the PICS panels has three main functions.

A. Pre-processing
B. Run of the analysis
C. Post processing

A. Pre-processing: - In this step, the input of required material properties, the geometry of the structure, meshing, boundary condition, and solution parameter setting is done.

B. Run to the analysis: - Monitoring the processing time and iteration steps for the analysis.

C. Post processing: - In this, the numerical values obtained from the analysis are plotted and the graphical visualization of the result values is done.

Steps for the FEM analysis

Step1: Geometry of PICS PANEL is formed in SOLIDWORKS software package. It has been presented in Figure 3.20. Then the geometry is exported to the ANSYS workbench software either through step file or IGES file.

Step2: Then the material properties are assigned to the various elements of PICS panels as shown in figure 3.21.

Step3: Various supports, loadings & monitoring points details are defined. (Figure 3.22)

Step4: FEA meshing parameters are defined for the prototype and the mesh is generated accordingly. (Figure 3.23)

Step5: Then the FEA non-linear analysis is Run. The FEA non-linear static analysis calculates the effects of steady loading conditions on a structure. Static analysis is used to determine the displacements, stresses, strains, and forces in structures or components by loads.

Step6: After the FEA nonlinear static analysis is completed then results are shown in the Ansys Post processing part. Then the plot for stress-strain, load vs displacement values at every step is plotted.

The analysis performed for the slab panel in flexure, punching, and sliding is displacement controlled and for wall panel in axial and diagonal compression is load controlled. For salb panel in flexure and in punching the midpoint, displacement is applied and the value of the load is finding corresponding to the displacement. For push off analysis, the displacement is given to the top wythe and the loads are found out. For wall panels load is assigned and the displacement at the boundaries are determined.

Figure 3.20: construction of 3D geometry

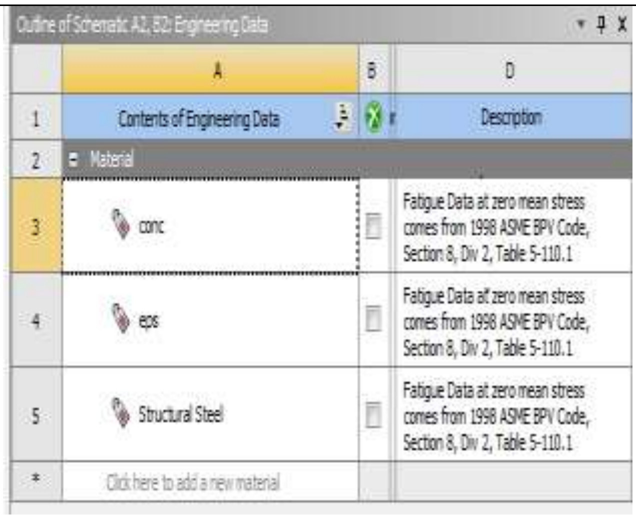


Figure 3.20: material properties in ANSYS

Figure 3.21: Defining boundary conditions

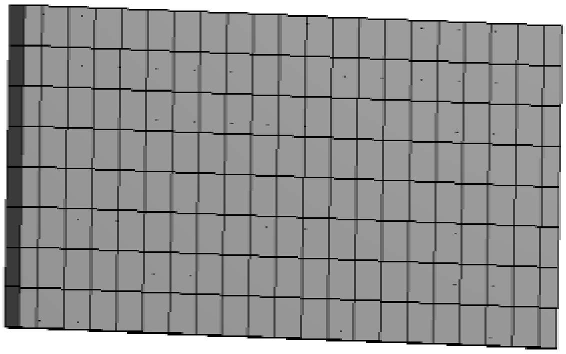


Figure 3.22: Meshing of structural components

3.13 METHODS FOR NON-LINEAR SOLUTIONS: -

The finest thing in ANSYS is the simplest technique of evaluating the NL structural performance through FEM and its progressive loading standards. ANSYS provides different methods for evaluating non-linear mathematical equations (NLME) viz Newton-Raphson Method (NRM), Modified Newton-Raphson method (MNRM), Arc Length methods, linear method, etc. Amid NRM & MNRM are most frequently applicable approaches. In our current FEA analysis, NRM is applied for evaluating the concurrent equations. NRM is an iterative technique for evaluating NLME. One of such tactics to get NLME is to split the force applied into a sequence of force progressions. These force progressions can be functional in two ways. The 1st one is to apply load in several load steps and the second one is to create several sub-stages within a load stage. Achievement of every respective progressive solution led to a software matrix of stiffness alteration to replicate NL variations in structural strength prior to the scheduling of succeeding force progression.

The ANSYS package overcomes this trouble by means of Full NRM, or MNRM, which determinate the solution to equilibrium convergence (under the applied tolerance limit) at the end of each force progression. For Full NRM, it obtains the following set of NLME:

$$\mathbf{K_{(p)}\,\Delta_p = q - f_{(p)}} \quad (3.7)$$

where, $K_{(p)}$ is the matrix of stiffness, relating force progressions to deflection progressions.

Δ_p is the deflection progression for force progression,

q is the vector of total applied joint forces,

$f_{(p)}$ is the vector of internal joint forces,

p is the deflection of structure earlier to force progression,

figure 3.9 illustrates the use of NR equilibrium iterations in NL analysis. Earlier each step, the NRM assesses the out of balance force vector, which is the variation among the restoring forces (the forces corresponding to the element stress) and the applied force. The software package then accomplishes a linear solution, by means of the out of balance forces, and evaluates for convergence. The out of balance force vector is reexamined if the convergence standards are not fulfilled, the matrix of stiffness is restructured, and a new solution is obtained. The iterative process lingers on until the converges of the solution. But sometimes, most time-consuming part of the Full NRM solution is the re-calculation of the matrix of stiffness K (pi−1) at each iteration. In many cases, this is not necessary and we can use matrix K (p0) from the 1st iteration of the step.

$$\mathbf{K\ (p_i-1) = K(p_0)} \quad (3.8)$$

The MNRM is shown in Figure 3.19. Comparing Figure3.10 and Figure 3.9, it is apparent that the MNRM meets more slowly than the original Full NRM. But a single iteration cost less computing time because it is essential to accumulate and eradicate the matrix of stiffness only once. I observe a careful balance of the 2 strategies is typically adopted so as to provide the most effective performance for a specific case. Usually, it's counseled to start out an answer with the initial NRM and later, i.e. close to extreme points, switch to the changed procedure to avoid divergence.

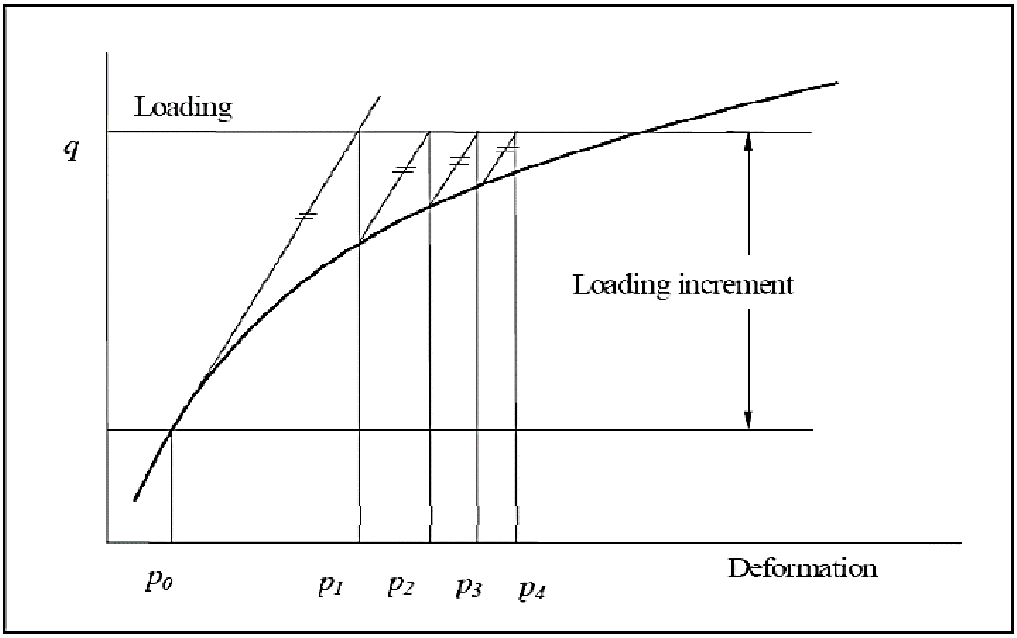


Figure 3.23 Modified Newton-Raphson Method

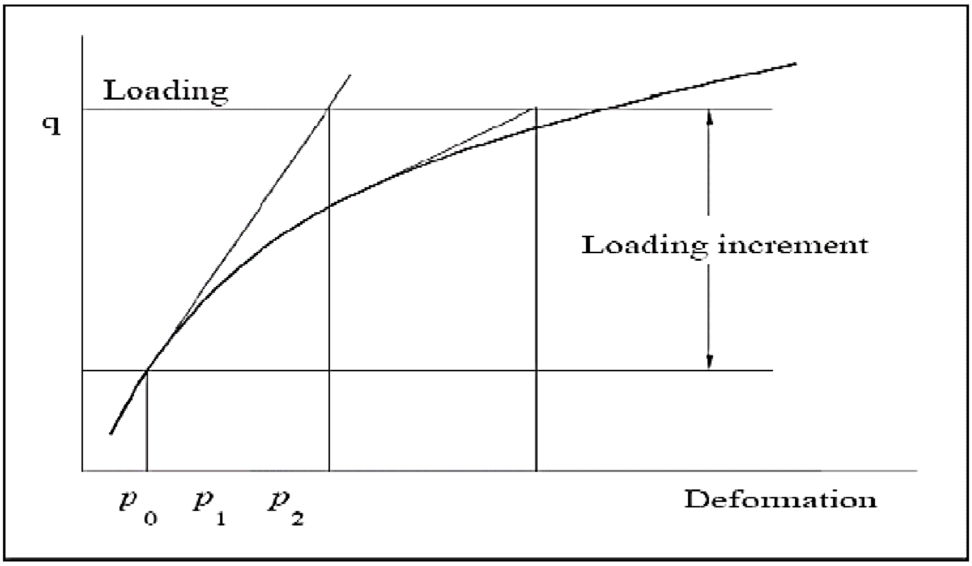


Figure 3.24 Full Newton-Raphson Method

Chapter 4: RESULTS OF FEM ANALYSIS

In this current study, the performance of PICS structural boards whose modeling details are discussed in chapter 3 is deliberated here. The results of the FEA studies are plotted and compared with the experimental study. The objective of the work is to see the variation of load with the displacement for all the analysis conditions i.e. for the wall as well as for slab panels. Also, to plot the moment-displacement curves, Maximum Principal strain variation with the load and how the average contours of Von Mises strain represent a crack pattern in slab panels only for flexure and punching is another objective of the study.

In this chapter, the results for FEM study performed for the study of PICS panels for slab and wall are discussed. The study discussion for the analysis is divided into three parts that are:

A. FEM analysis of slab board under flexure and punching

B. FEM analysis of slab board under push-off analysis.

C. FEM analysis of wallboard under axial and diagonal compression.

The use of ANSYS WORKBENCH 15.0 is made for the analysis of PICS as a panel under the extension of static load analysis. The analysis is done implicitly by generating the boundary conditions on the body surface through the command edge split. The Displacement controlled analysis is done for slab panels in flexure, punching and shear sliding and force-controlled analysis is done for wall panel in axial and diagonal compression. Full Newton-Raphson iterative method is applied for analysis and smeared cracking prototype for concrete is used.

The structural response at every step of iteration is recorded. The results come out from the analysis are validated with the experimental results performed by "J. Danial et.al (2015 & 2019)" for flexure, punching, push off analysis and by "Gara et.al. (2012)" for axial and diagonal compression.

4.1 FEM ANALYSIS OF SLAB BOARD UNDER FLEXURE AND PUNCHING: -

For the 1st part that the load-displacement curve, moment-displacement curves are plotted and the validation of the prototype is done. Also, the value of Maximum Principal strain variation with the force is plotted by dividing the top and bottom wythe in 3- 3 parts for four-point bending as shown in figure 4.1 and by dividing the top and bottom wythe in two- two parts for punching as shown in figure 4.2. Then the complete average contours of Von Mises strain are plotted which represents how the strain varies in the complete board and how the contours are representing the crack pattern. The analysis done is useful in determining the degree of composite action (DCA) of the slab panel. Since DCA is the most essential component while the analysis of panels as slab panels. It helps in determining whether the top and bottom wythe of the panel is acting as a single unit or not. By this means it can be determined up to how much thickness of the central EPS core the strain variation in the panel is linear up to the elastic stage of the panel. To determine the thickness of the EPS core is very important because EPS is a lightweight material and the least value of strain is experienced by the central homogeneous portion about the neutral axis. It the panels performed up to a required DCA then the neutral axis will pass from the center of the EPS core and shear connectors are useful in transferring the strain and the panel is used as slab panel. Figure 4.1 & 4.2 shows the strain measuring points for the slab panel prototype whose value is recorded and determined for the analysis. The value strain measured is the value of maximum principal strain.

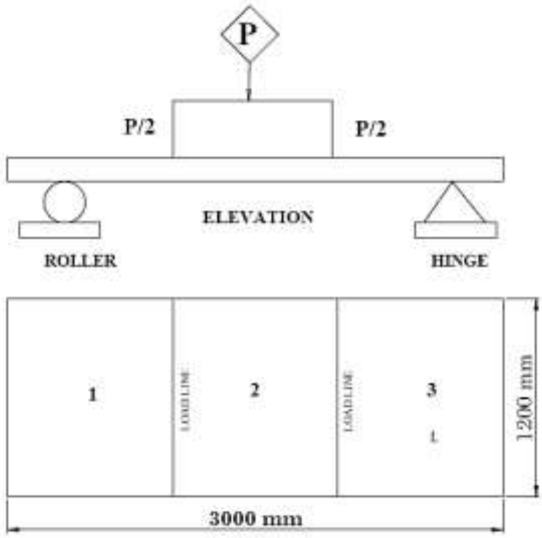


Figure 4.1 FEA illustrative view structured for flexure

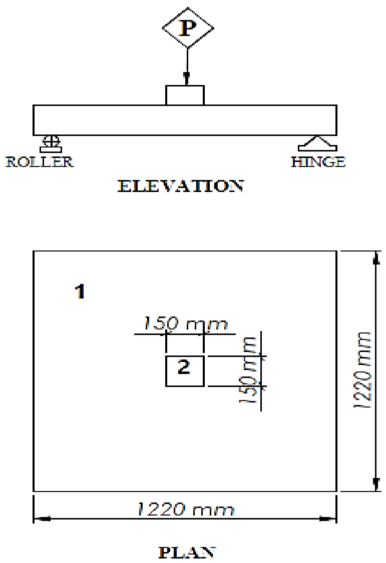


Figure 4.2 FEM structured for analysis in illustrative view punching force test

4.1.1 Force vs displacement behaviour in punching and flexural test: -

From the FEM analysis, it can be concluded that the FEA prototype is capable of forecasting the force vs displacement performance in case of punching as well as flexure which is evident from the figure

4.3 and 4.4 respectively. In case of flexure, the prototype behaves linearly up to 14.5 kN of force which is 12.5 kN in case of experimental testing whereas in case of punching the force is linearly up to 19 kN of force in FEM prototype which is 17.5 kN in experimental testing. When the board reaches the maximum elastic resistance to deformation the formation of plastic hinges starts forming in the prototype. It is the phase where the formation of 1st crack starts. After that, the force progression causes more crack formation as well as widening of the previous cracks. Ultimately a phase is reached when the board is not able to take any force and reaches to the failure. The FEM prototype shows more strength than the experimental ones because the FEM analysis is done under control conditions in which micro-cracks, shrinkage, and possible creep effect is neglected. Also, in experimental studies the results are dependent on instrument calibrations as well as the composition of the material used for casting whereas in case of FEM analysis the results are dependent on material properties, forcing conditions, as well as solver type hence prototype, will act stiffer because FEM analysis is an iterative process. Also, figure 4.5 and 4.6 shows that how the deflection changes along the length.

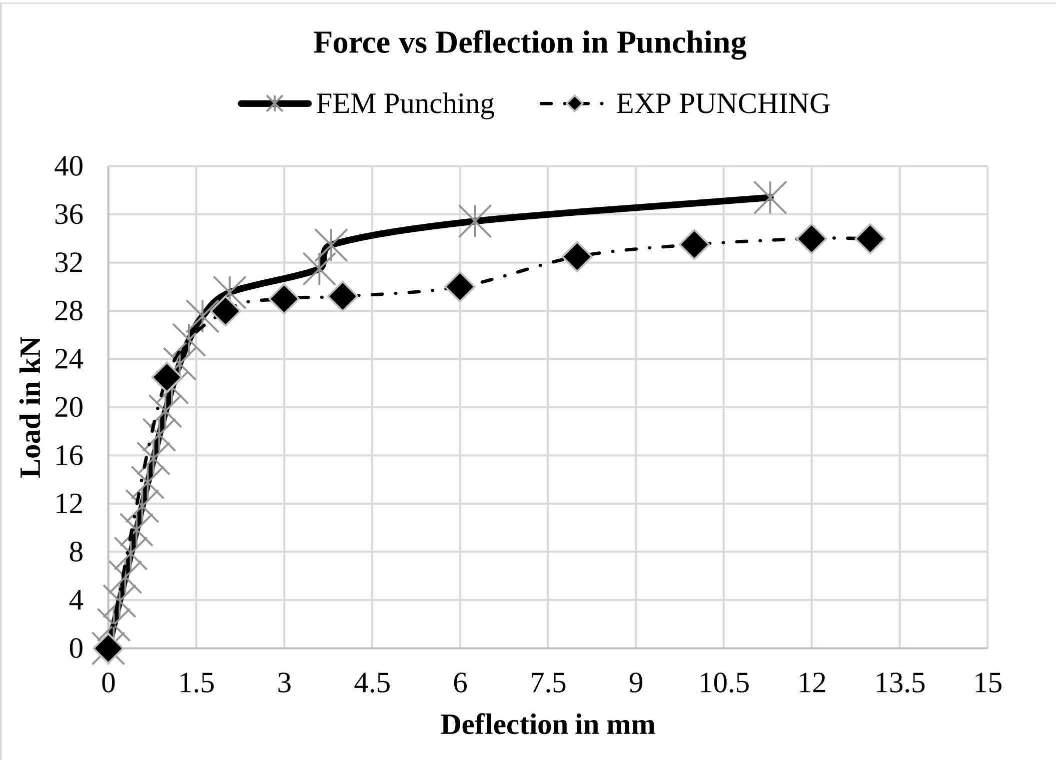


Figure 4.3: Force vs Displacement graph in punching

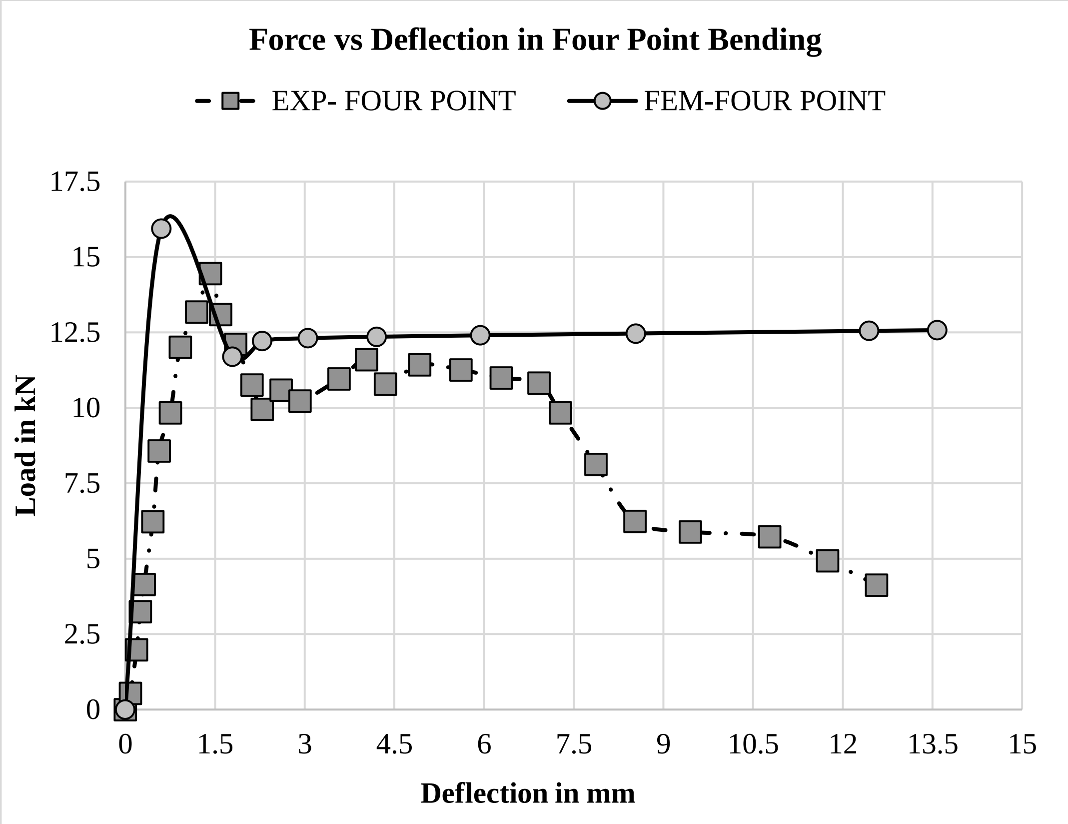


Figure 4.4: Force vs Displacement graph in flexure

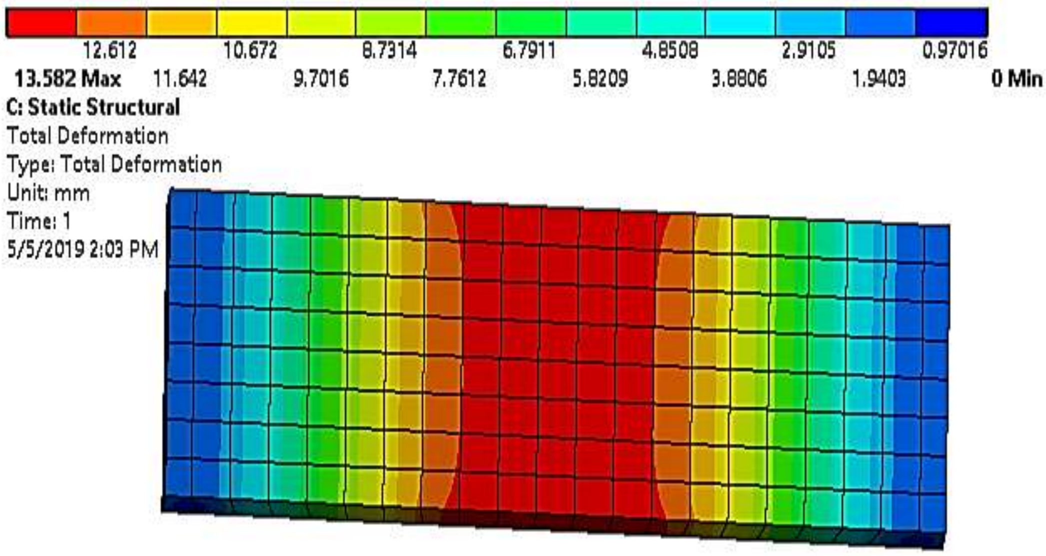


Figure 4.5: Displacement variation along the length in flexure

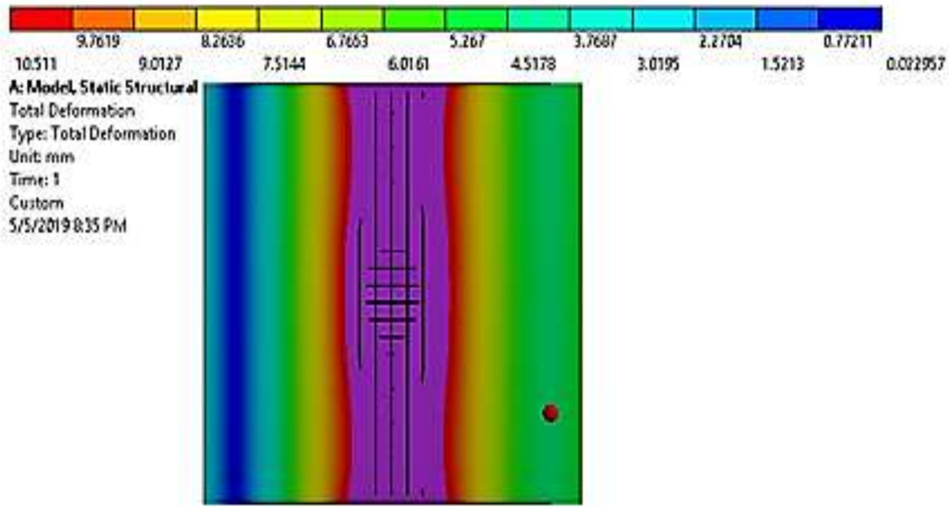


Figure 4.6: Displacement variation along the length in punching

4.1.2 Moment vs displacement behavior in punching and flexural test: -From the force coming from the analysis of the slab boards in punching as well as flexure the bending moment of the board is calculated and compared with the experimental bending moment of the board. Figure 4.7 and 4.8 shows that the moment coming from the FEM analysis is comparable with that of experimental analysis. The bending moment corresponding to 1st crack is 6.5 kN-m in FEM analysis which is 5.7 kN-m in experimental testing in flexure and in punching the 1st crack moment is 6.2 kN-m in FEM analysis which is 5.9 kN-m in case of experimental testing.

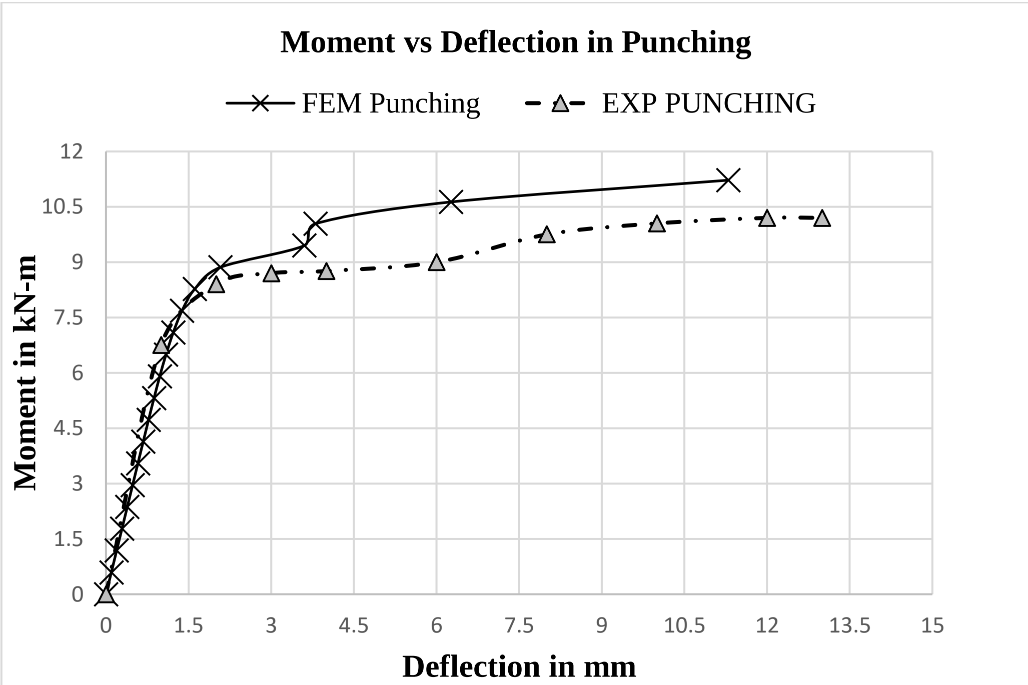


Figure 4.7: Moment vs Displacement graph in punching

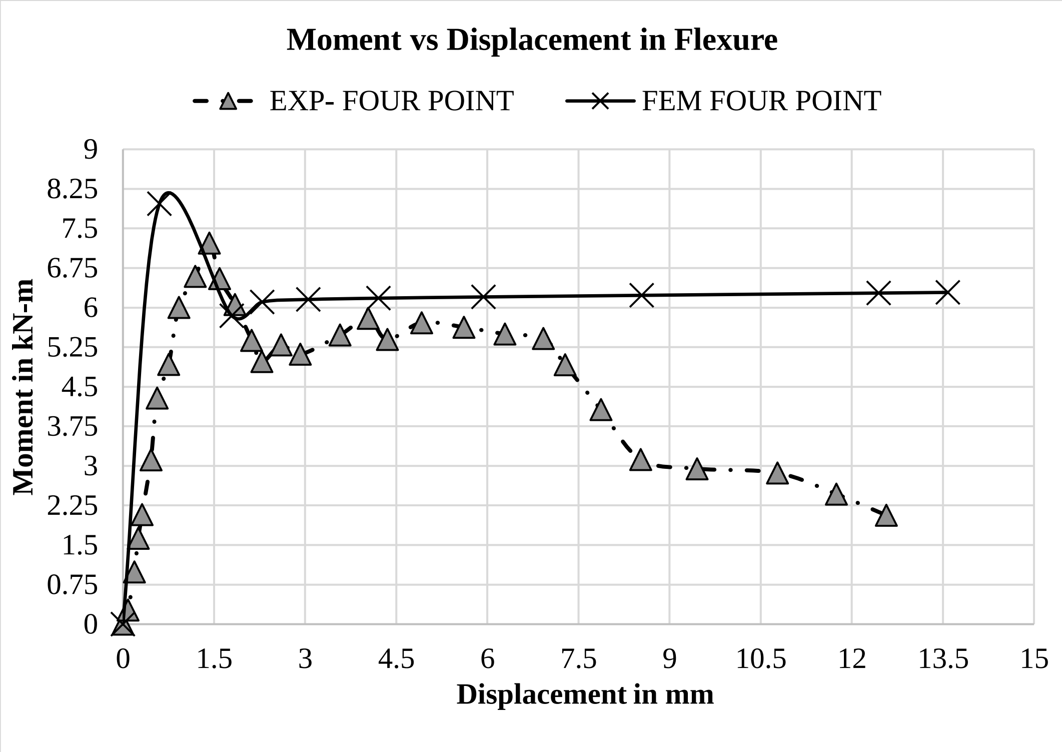


Figure 4.8: Moment vs Displacement graph in flexure

4.1.3 Force vs maximum principal strain performance in punching and flexural test:

Variation of strain along the length is measured in the top as well as in the bottom Wythe. By dividing the top and bottom wythe into 3 parts each in flexure which is the same case in an experimental analysis done by J. Daniel (2015) as shown in figure 4.1 and for punching the Wythe is divided into two parts each as shown in figure 4.2. The variation of maximum Principal strain is measured at these locations in fem analysis and then the results are compared. The results show that the strain for C1 & C3 locations are tensile and strain at C2 is compression which matches with the fem 1 and fem 2 positions in punching as shown in figure 4.9. Consequently, under the loading point, the stress in top wythe is compression in nature and at distances away from it is tensile in nature. This specifies that the plate (slab-board) bending is not cylindrical, because for cylindrical bending in the plate (considering homogenous and isotropic) only compression stress appears in extreme top fibres. The cause for this might be the partial moment retainment offered at the supported edges in punching. Figure 4.10 confirmations strain variations in bottom cement matrix skin. The stress in bottom cement matrix skin is tensile in nature. Reversal of strain contributes to the creation of cracks at other positions in bottom cement matrix skin that relieved the stress.

E variations measured for top and bottom skins of the slab board under flexure are presented in Figure. 4.11 & 4.12. The value of strain variation represents that top skins are exposed to compression stress and the bottom wythe is exposed to tensile stress. These studies reflect that; the plate bending is considered to be cylindrical till the constant bending moment region up to the point of stress-strain proportionality. Subsequently, at 1st crack force, there is a decrease in the value of strain measured.

This credits to broadening of a crack in bottom cement matrix skin which discharged stress in top cement matrix skin.

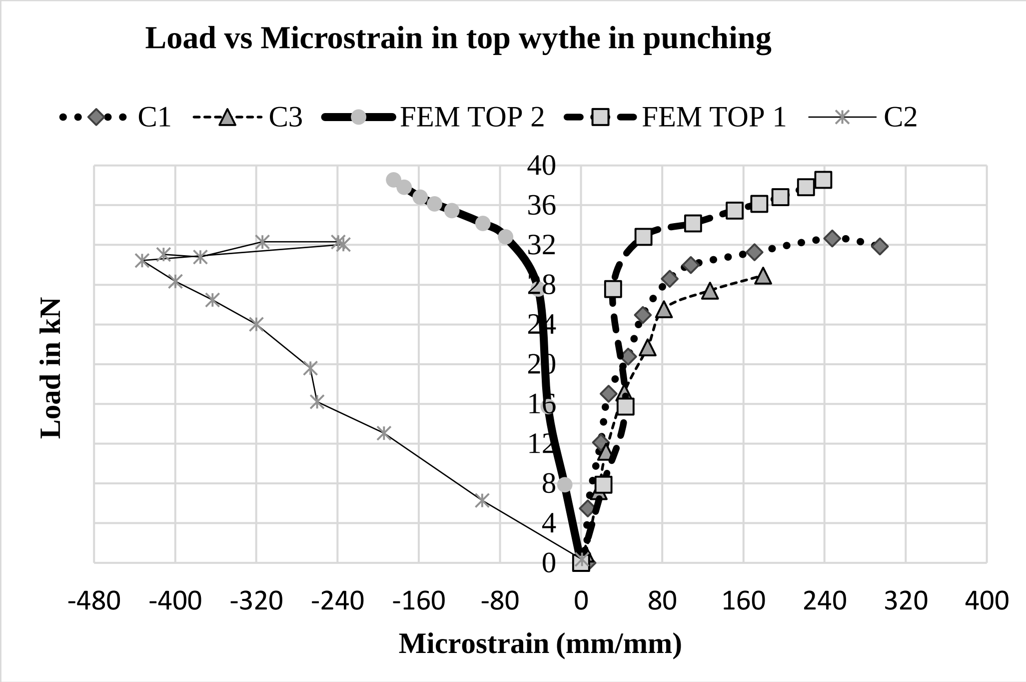


Figure 4.9: Microstrain variation in top wythe (punching).

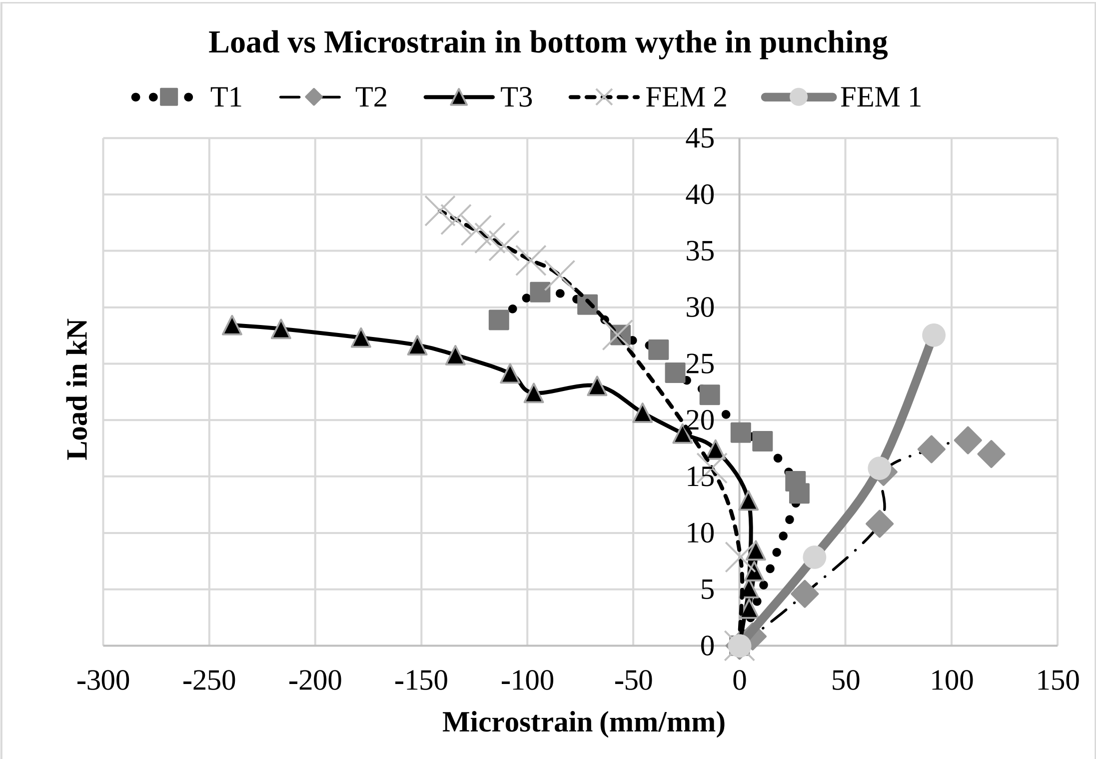


Figure 4.10: Microstrain variation for bottom wythe (punching)

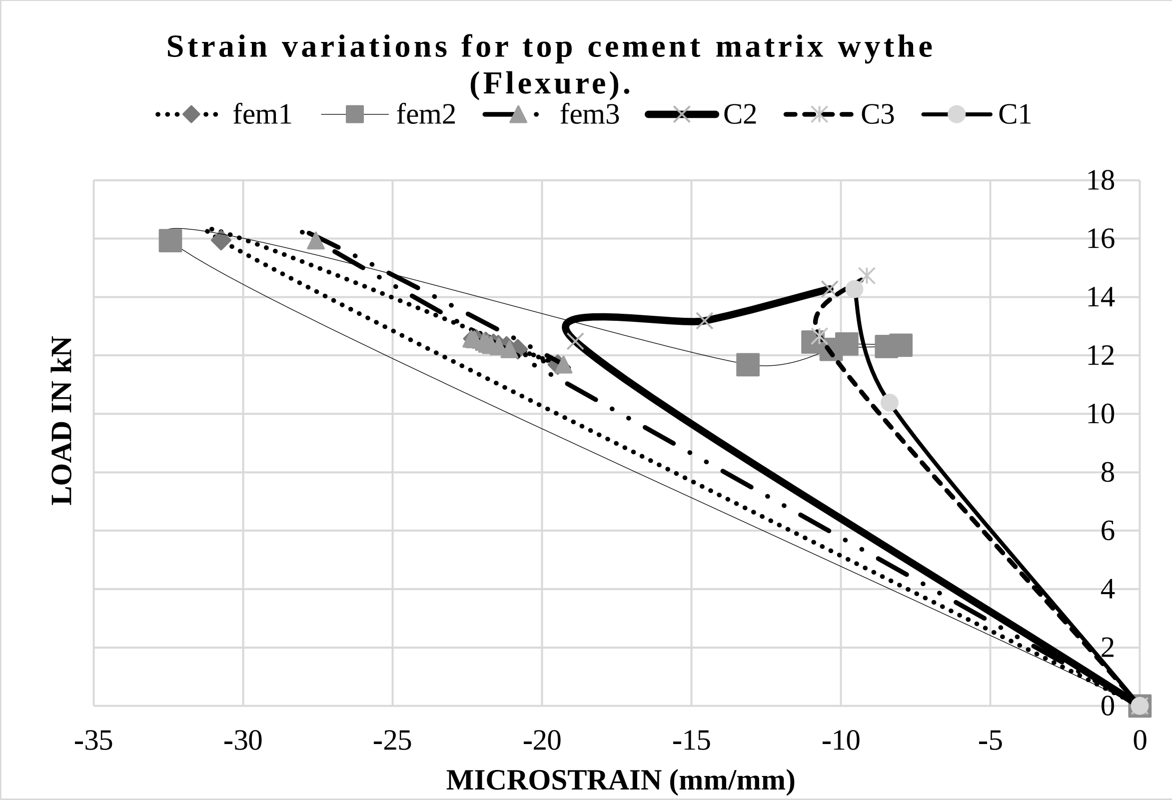


Figure 4.11: Microstrain variation for top cement matrix wythe (flexure)

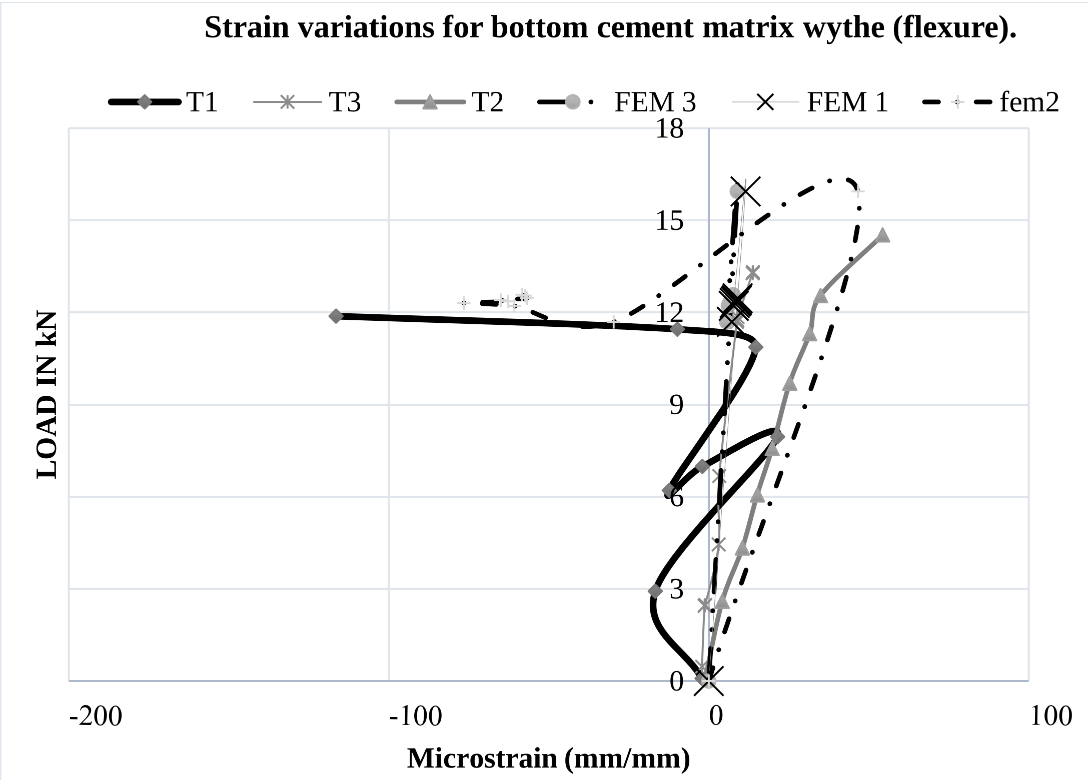


Figure 4.12: Microstrain variation for bottom cement matrix wythe (flexure)

4.1.4 Crack pattern:

The board analysed under flexure collapsed by founding inclined shear cracks where the prototype analysed for punching force failed by developing flexural cracks at the bottom wythe. From the FEA prototype, it is analyzed that the cement matrix sandwich slab board failed by establishing inclined cracks that have a tendency to connect with the nearest support and forced point. It is also highlighted that the general failure of the slab is not governed by shear failure. Yet, it is found from the present study that the cement matrix sandwich board failed by forming inclined cracks that have a tendency to link with the nearest support and forced point. After the creation of the inclined cracks, when the functional force is amplified, the size of the inclined crack enlarged deprived of developing new flexural cracks in the slab board. For prototype analysed for punching force, horizontal cracks by the side of the longitudinal direction at middle sheet wythe boundary were spotted. These cracks might be recognized due to negative bending moment formed due to the regular shape of cement matrix cover at edges of the boards. Hence, the PICS boards resemble the performance as of like RC slab. Figure 4.13, 4.14,4.15 and 4.16 depicts the failure crack patterns of PICS board under punching as well as flexure reported by J. Daniel et. al (2015) alongside the computed crack patterns and the Von Mises average strain contours estimated from the NL finite element analysis procedure, immediately prior to calculated failure. For both slab cases, it can be seen that the FEM analysis was generally proficient of capturing the locations and development of the dominant shear cracks, as well as meaningful estimates of secondary cracking.

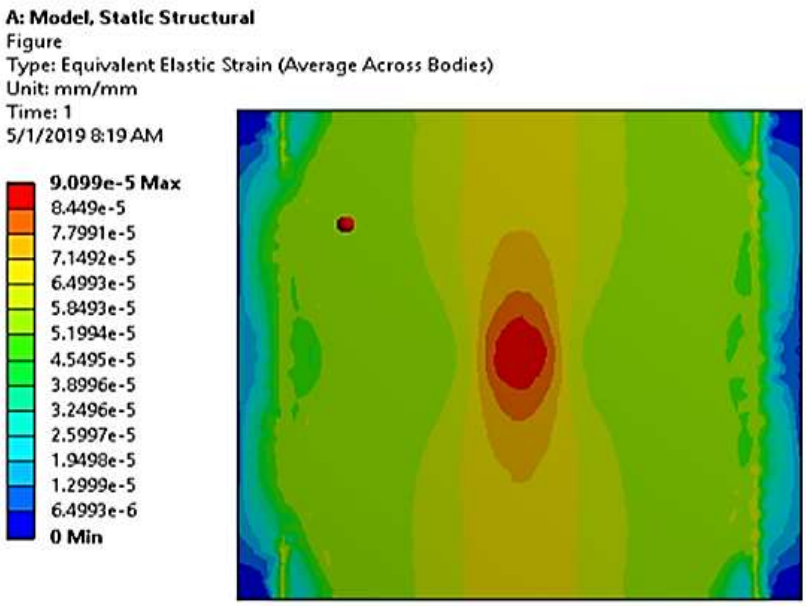


Figure 4.13: Cracks observed on bottom wythe (for punching force). (FEM)

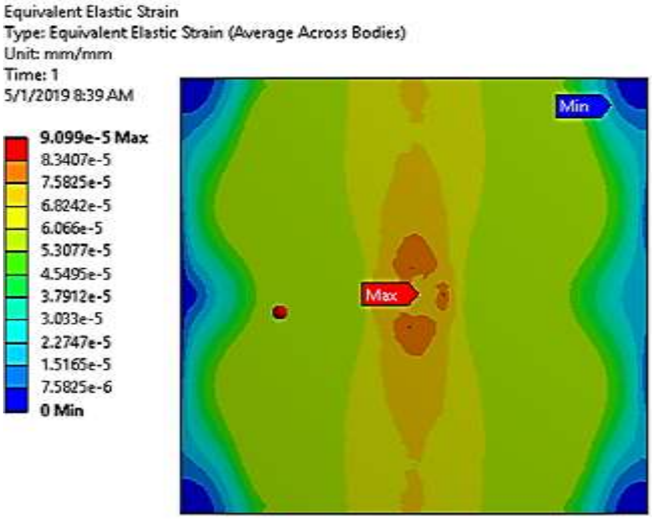


Figure 4.14: Cracks observed on top wythe (for punching force). (FEM)

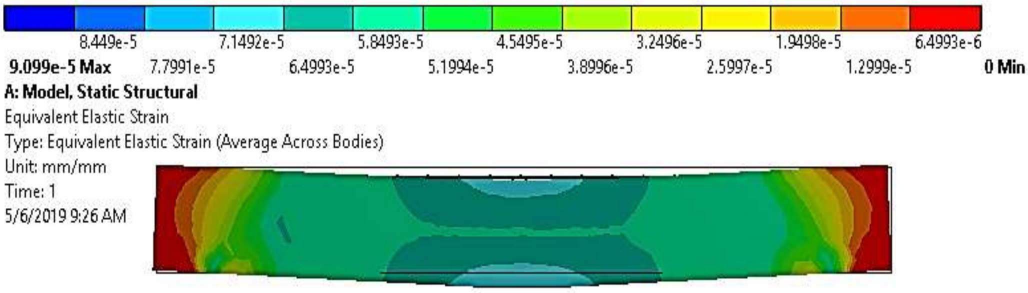


Figure 4.15: Shear cracks in Punching (FEM)

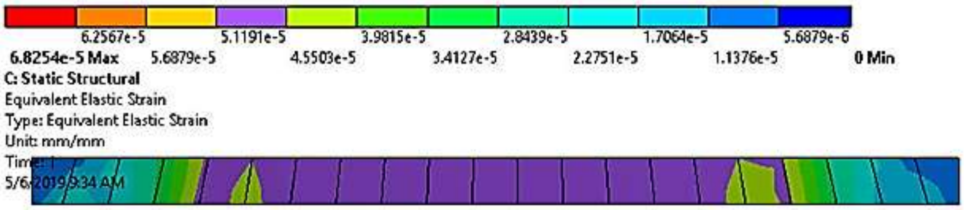


Figure 4.16: cracks in four-point bending (FEM)

4.2 FEM ANALYSIS OF SLAB BOARD UNDER PUSH-OFF ANALYSIS: -

The FEM analysis of slab board is done and the failure pattern, through depth shear capacity and force vs comparative displacement were analysed from the push offloading test and the results obtained are validated from the experimental results performed by J. Daniel et.al. The analysis shows that the sliding occurs at the interface between the cement matrix wythe and the EPS middle sheet.

4.2.1 FAILURE PATTERN AND THROUGH THICKNESS SHEAR CAPACITY: **-** For FEM-A and FEM-B a frictional contact is considered. When the displacement is applied at top wythe by considering bottom wythe fixed so that the displacement comes in is comparative displacement w.r.t the bottom wythe. The results show that as the force increases the bond between the EPS middle sheet and the top wythe losses its resistance to deformation and causes the sliding of the top wythe. The bond shear capacity decreases until the failure. It was also seen that no shear deformation occurs into the middle isolated middle sheet. This indicates the central middle sheet is having more shear capacity than that of the bond at cement matrix wythe and the EPS middle sheet. One more thing comes in that the loss of bonding between the cement matrix and the EPS middle sheet is not sudden but gradual. FEM-C and FEM-D show that the specimen with an empty central portion fails by the buckling of truss shear linkers under shear slide forced. During the analysis, the truss shape steel shear linkers experience compression as well as tensile force depending upon the direction of inclination. Hence, in total the main reason for the failure of the specimen in the push-off shear loading test is the buckling of the truss shape steel shear linkers.

It was also coming under consideration that the shear capacity of the PICS boards increases either by decreasing the gap between the cement matrix wythe or by reducing the depth of the EPS middle sheet. By doing this length of truss shape steel shear linkers effective in buckling decreases for the same thickness of truss shear Fe connector and capacity of taking force increases. Table -4.1 shows how FEM-B and FEM-D are having more value of P_{use} then FEM-A and FEM-C. Also, figure 4.17 to 4.20 shows the failure pattern in FEM-A, B, C, and D.

Table 4.1: FEM results of PICS specimens in Push off test

S. no	Prototype name	Depth of EPS middle sheet	The total depth of specimen	Through depth shear capacity	Mode of failure
		(C) (mm)	(t) (mm)	P_{use} (kN)	
1	FEM-A	100	150	25	Buckling of shear connectors
2	FEM-B	50	100	35	
3	FEM-C	NO MIDDLE SHEET	150	10	
4	FEM-D	NO MIDDLE SHEET	100	20	

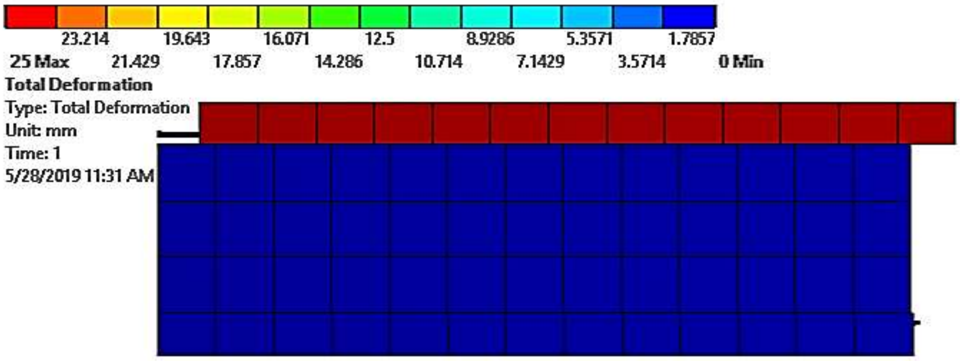


Figure 4.17: Failure pattern in FEM-A

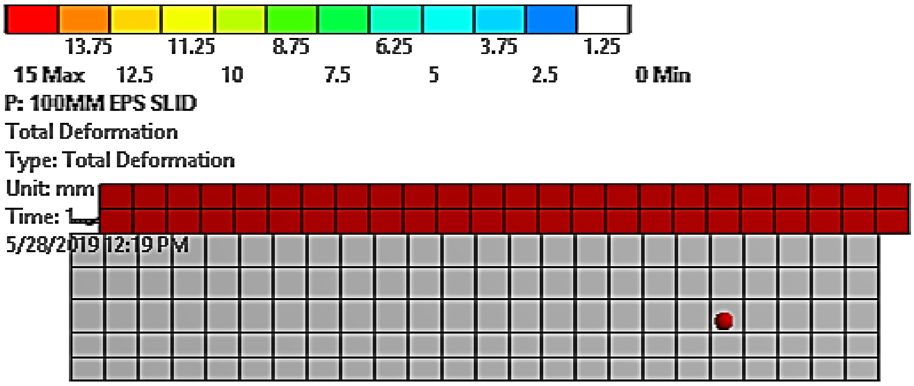


Figure 4.18: Failure pattern in FEM-B

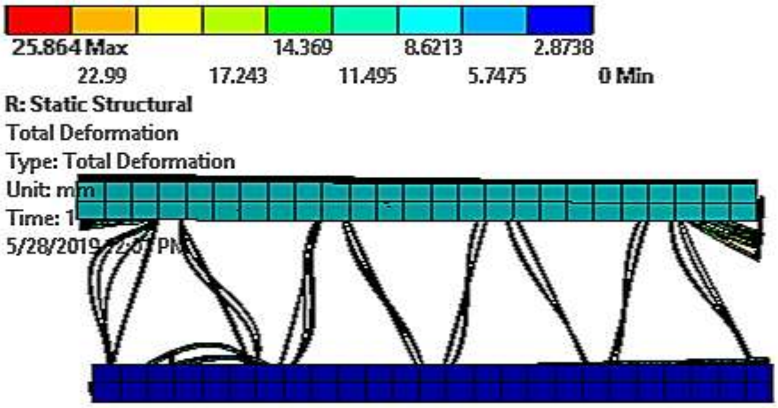


Figure 4.19: Failure pattern in FEM-C

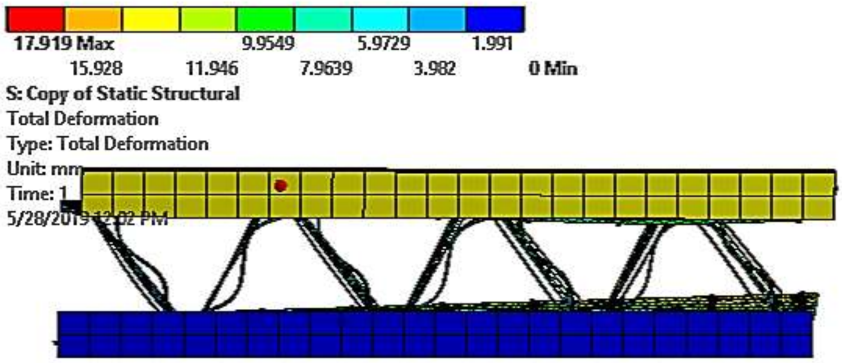


Figure 4.20: Failure pattern in FEM-D

4.2.2 Force vs comparative displacement: - For all the four push-off shear sliding cases the behavior of force vs comparative displacement is trilinear. The 1st linear portion highlights the gentle loss of bond shear capacity happens at the interface of middle EPS middle sheet and cement matrix wythes and deformation of the isolated middle sheet under shear forced effect. For the second linear slope, the role of Fe truss shear linkers to withstand the force applied to accompany with the remaining bond resistance to deformation at cement matrix skin-to- middle sheet interfaces are responsible. The third linear slope shows the behavior of the PICS board after buckling of truss shear linkers under compression. It was observed that FEM-B is having more resistance to deformation then FEM-D due to the EPS middle sheet. The same is happening FEM-A and FEM-C. figure 4.21 to 4.24 shows the force vs comparative displacement for FEM-A, B, C, and D.

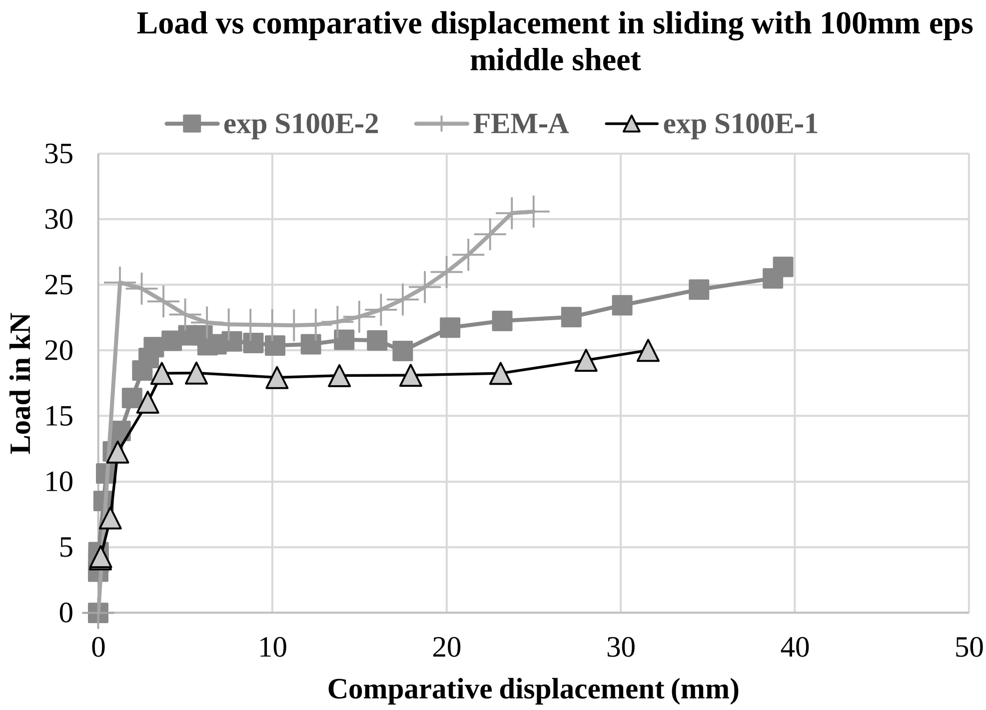


Figure 4.21: Force vs comparative displacement FEM-A

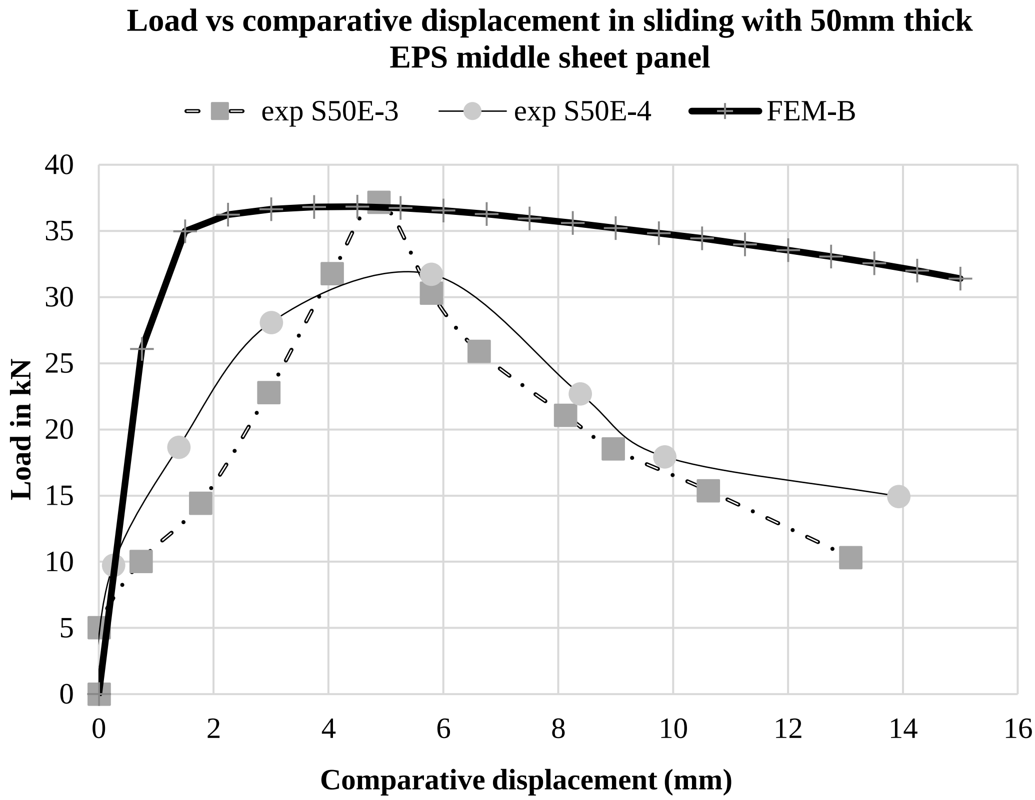


Figure 4.22: Force vs comparative displacement FEM-B

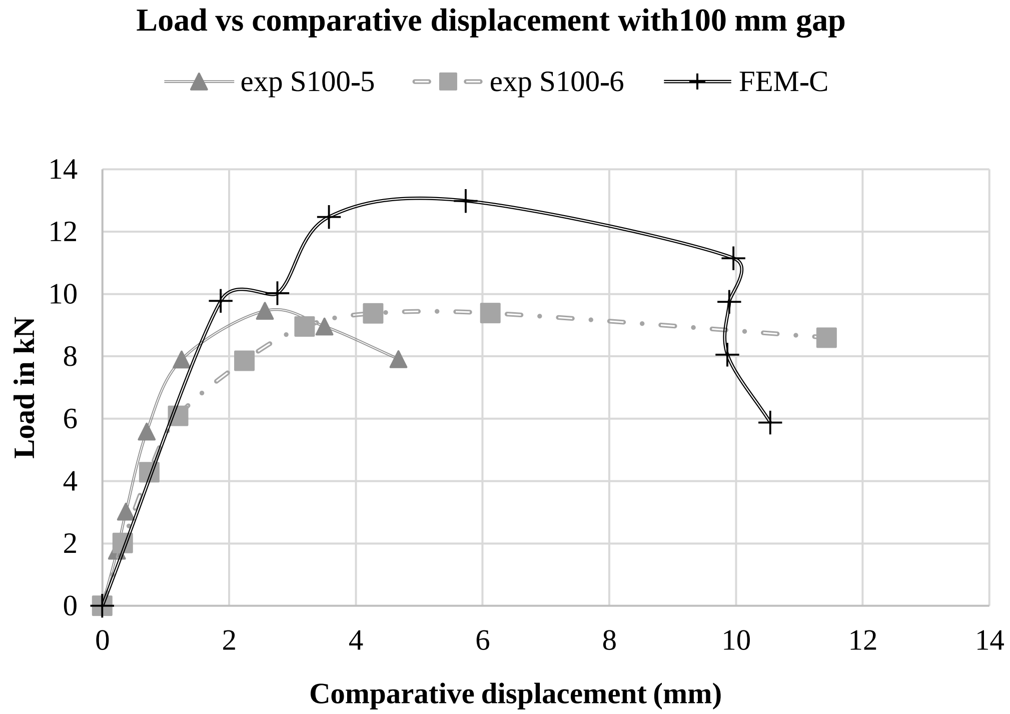


Figure 4.23: Force vs comparative displacement FEM-C

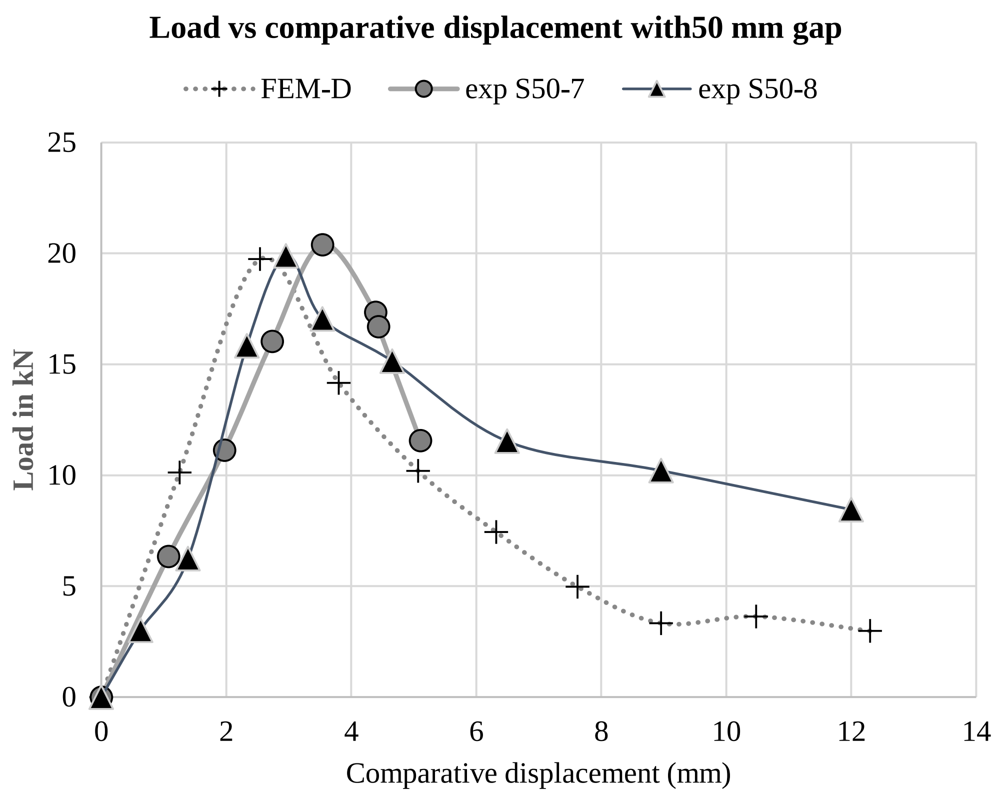


Figure 4.24: force vs comparative displacement FEM-D

4.3 FEM ANALYSIS OF WALL BOARD IN AXIAL AND DIAGONAL COMPRESSION: -

In these forced cases the main force is taken by 70 mm of cement matrix wythe. The failure pattern and force vs displacement curve for the specimen are given below.

4.3.1 Failure pattern: **-** Initially, both the cement matrix wythe are experiencing compression force but as the force increases the outer wythe experience tension and the inner wythe experiences compression. As a result of which outer wythe will go under elongation and the inner wythe will go under shortening deformation in axial force. It's also been seen that by increasing the thickness of EPS middle sheet, slenderness ratio decreases and thus the force carrying capacity increases. In diagonal compression initially, the horizontal elongation and the vertical shortening were not the same but it is lesser. After some force progression, this difference got neutralizes. In both these force case, the force causes the establishment of weak zones and this zone exceeds by force progression and ultimately this causes the failure of the specimen. The failure is due to the progression of the stress of the element than that of the bearing capacity. Table-4.2 summarizes the ultimate force capacity and figure 4.25 to 4.28 shows the failure pattern for axial and diagonal compression.

Table-4.2 FEM results of PICS specimens in Axial and Diagonal compression

S. No	Specimen ID	The thickness of EPS middle sheet © (mm)	ultimate force Pu (kN)	Testing condition (compression)
1	FEM-E	80	725	axial
2	FEM-F	120	775	axial
3	FEM-G	150	980	axial
4	FEM-H	80	350	diagonal

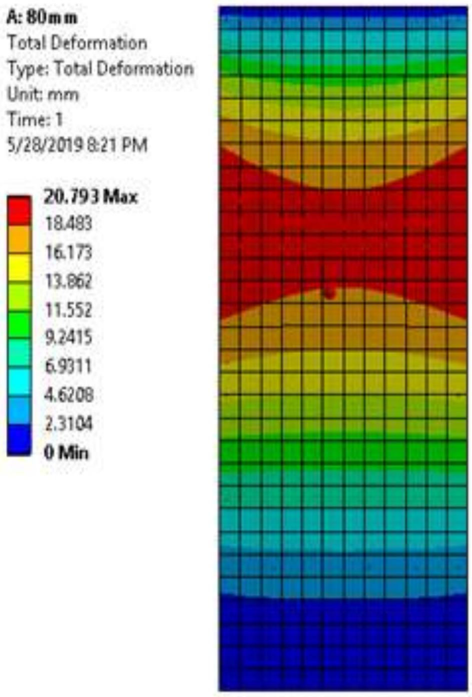


Figure 4.25: Failure pattern in FEM-E

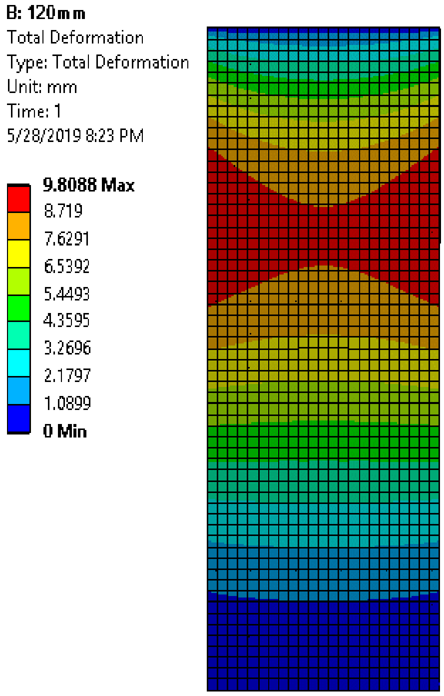


Figure 4.26: Failure pattern in FEM-F

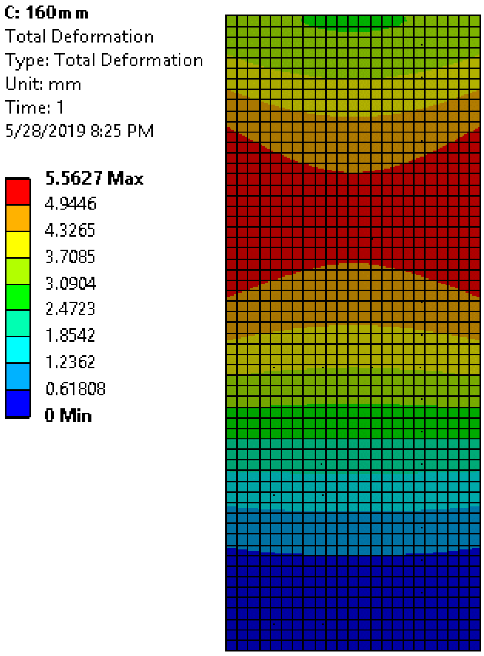


Figure 4.27: Failure pattern in FEM-G

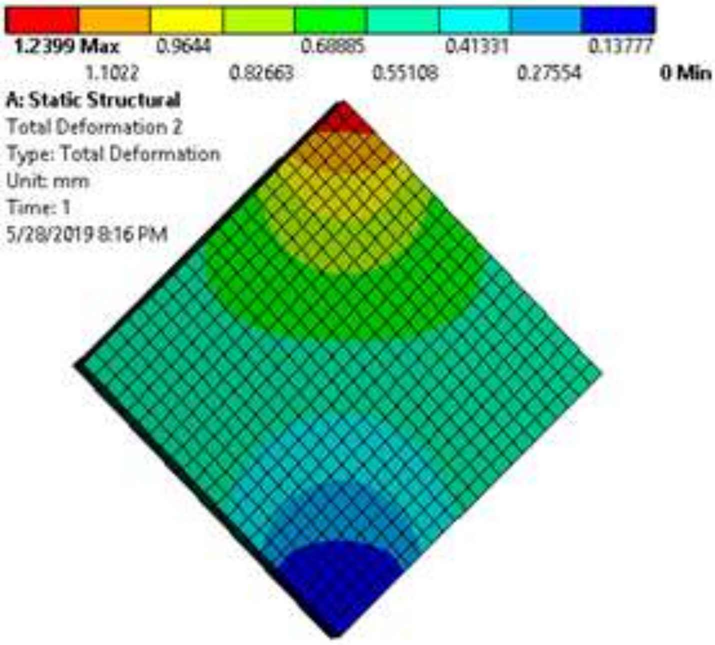


Figure 4.28: Failure pattern in FEM-H

4.3.2 Force vs displacement*:* **-**

The FEM analysis is performed by considering the non-linear functioning of the board. The analysis shows that with the increase in EPS middle sheet depth ultimate pressure taking the capacity of PICS boards increases for axial force but the failure of the board changes from ductile to brittle. In diagonal compression, one diagonal will go under tensile rupture and the other diagonal will go under compression crushing ultimately causes the failure of the board. Figure 4.29 to 4.32 shows the force-displacement curve for force cases.

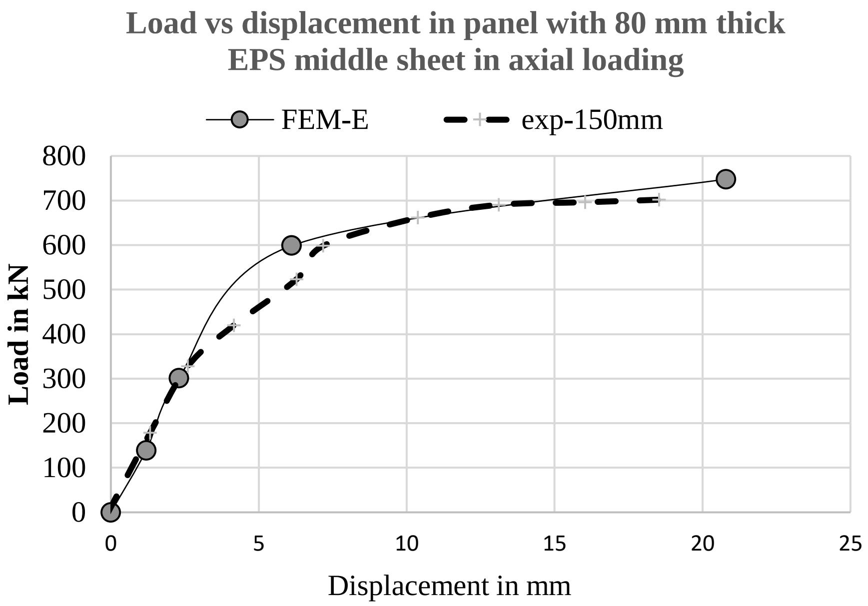


Figure 4.29: Force vs displacement curve for FEM-E

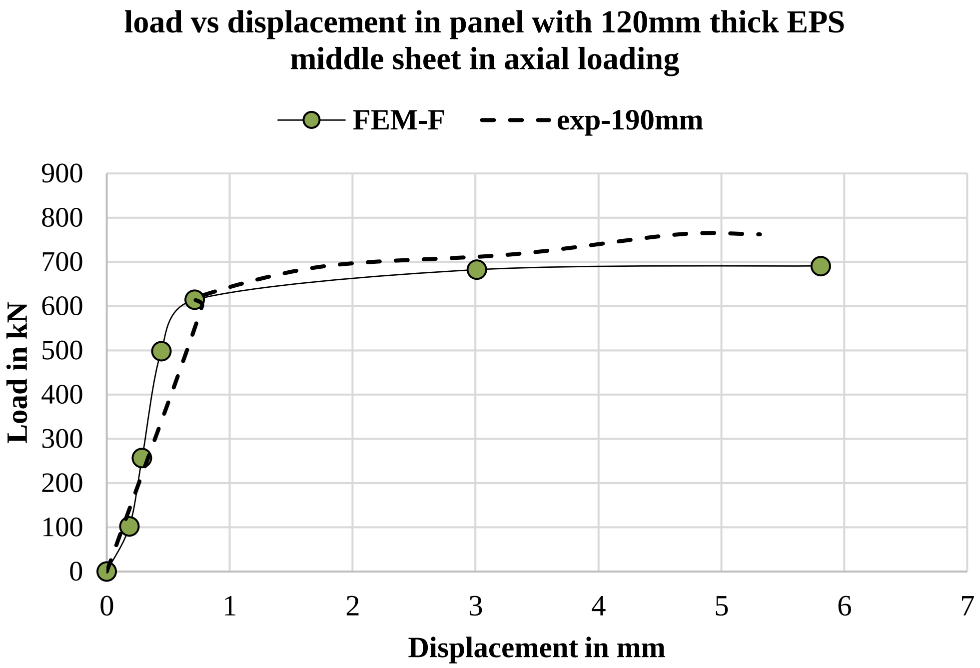


Figure 4.30: Force vs displacement curve for FEM-F

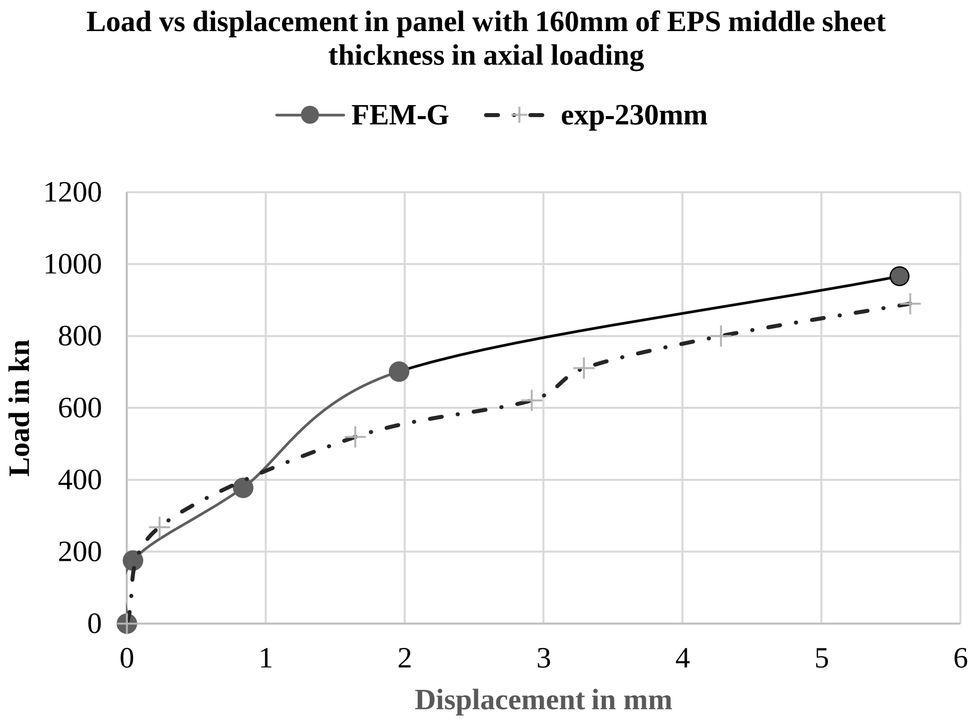


Figure 4.31: Force vs displacement curve for FEM-F

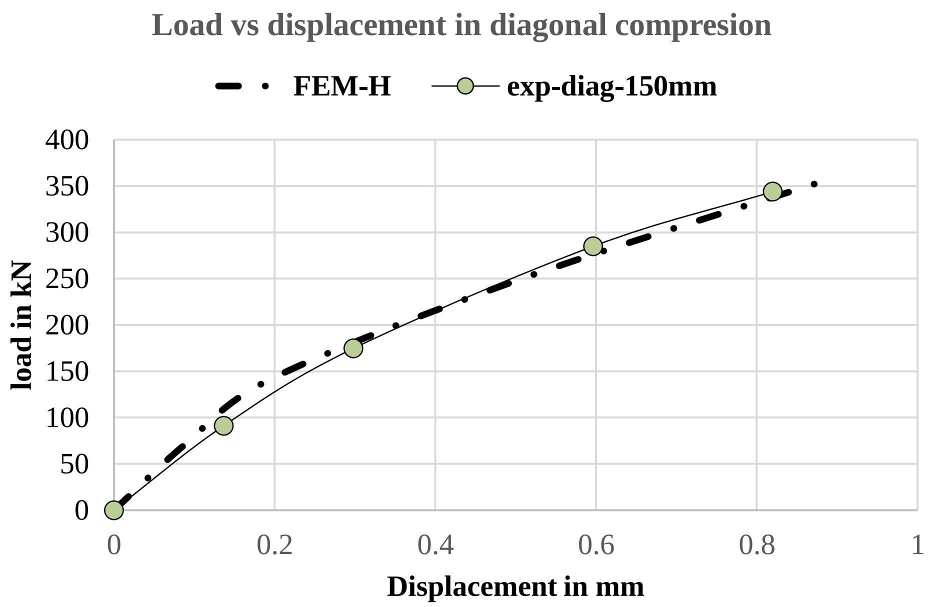


Figure 4.32: Force vs displacement curve for FEM-H

Chapter 5: CONCLUSIONS

5.1 GENERAL: -

In the present study, the FE analysis of cement matrix sandwich panels with EPS boards is done for flexure, punching and push-off analysis by considering the panels as slab panel. By considering the panel as wall panel axial and diagonal compression behavior is also studied. The following conclusions are highlighted from the present study:

1. Finite element analysis for precast in-situ concrete sandwich panels shows a close agreement with the experimental one for both slab as well as wall panels. For the prototypes analyzed for punching and flexure the load carry capacity is 10% and 12.5% more than the experimental one.

2. Under flexure loading the mode of failure is due to shear (inclined) cracking whereas in punching load the mode of failure is due to both shear (inclined) as well as radial cracking in top and bottom wythe. For the slab panel analyzed for flexural loading the bending is unidirectional but for punching loading the bending is bidirectional.

3. For precast in-situ concrete sandwich panels subjected to push-off loading the presence/absence of middle core, thickness of middle core and distance between the top and bottom wythes effects the shear strength of the panel. The prototype with least depth of EPS core have the highest shear strength load capacity and the prototype with maximum vacant space in between the top and the bottom wythes have the least shear strength load capacity.

4. Under push off loading the main failure is governed by the buckling of shear connectors. The initial strength is provided by the bond between the EPS core and the concrete wythes. After, certain load the bond between the concrete wythe and the shear connector loses its strength and the strength is governed by the shear connectors.

5. For wall panel subjected to axial and diagonal compression the force carrying capacity increases with the increase in the thickness of EPS middle sheet as the slenderness ratio for the wall decreases with the increase in EPS core thickness.

6. Also, the mode of failure changes from ductile to brittle failure with the decrease in the slenderness ratio. The composite action between the outer and the inner wythe of the wall panel changes from fully composite to partially composite under axial forces due to the shear linkers are not able to transfer the force effectively from outer to the inner wythe.

5.2 FUTURE SCOPE: -

Hence, it can be concluded that the FEM analysis in ANSYS WORKBENCH 15.0 correctly represents the functioning PICS board but more research in need to be done. For actual building scenario, the response of the PICS boards for perpendicular and parallel in-plane forces is greatly affected by the inclusive size of the slab, walls & spacings and vents for doors & windows. Also, how the board joints configuration behaves under seismic forces need to be investigated.

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ANNEX-I: CONSTRUCTION METHODOLOGY

The construction of the house with the help of PICS boards has to follow the following steps.

A.1 FOUNDATION: -

- Diggings, even out, pointing for the plinth and packing with sand deposits and P.C.C shall be applied.
- Then the reinforced steel bars provided at suitable spacing along the support beam to carry the boards. Then the pouring of cement matrix is done to the beam.

Figure. A 1.1: Groundwork of foundation (EVG)

A.2 FIXING AND FORMATION OF WALLBOARDS: - The 1st step is to position two boards such that can form an edge joining sand the adjacent boards are fastened collectively, properly by means of a pneumatic tie tool. After that, the board tops can be transported on edge joining forming line using proper bracing. This is shown in figure A 1.2. Many factors, like. board height, wind conditions, etc. effect the type of braces. Figure A 1.3 shows the bracing of the board. Bracing is done on the opposite side of the side which is 1st shotcrete. This is shown in figure A 1.4. At edge joints, right-angle wire mesh is added inside and outside (called the edge joining mesh), and tied to the board mesh and strips of suitable size of cover mesh (the so-called splice mesh) are used to reinforce board beams.

Figure A 1.2. Placement of 3D wall boards for construction (EVG)

Figure A 1.3. Erection of 3D Boards (EVG)

Figure A 1.4. Prop supported for slab construction (EVG)

A.3 OPENINGS: -Openings for windows and doors are to be made out either earlier or later board assembly. Several different approaches are used for the openings. The recommended board cutting method is by the usage of electric saw with a metal sniping blade (in figure A 1.5 & A 1.6) with the lowest diameter of 10 cm. If the above method is not possible at a job site due to any reason, then to snip the mesh wires a pair of bolt cutters and hand saw is used to dissect the board. After the formation of required size opening, a band is placed along with the diagonal overhead and underneath the edge joining to prevent cracks. Figure A1.7 shows opening inboard.

Figure A.1.5. 3D Board cutting method (EVG)

Figure A.1.6. Prototype building with openings (EVG)

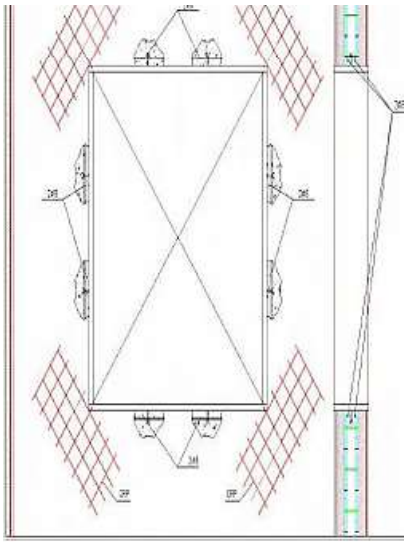

Figure A.1.7. openings in wall (BMTPC)

A.4 UTILITIES: **-** Once boards are perfectly set up at their required positions, the establishment of utilities starts. The space between the EPS layers & sheet of wire lattice gives astounding zone to enclosing both electric channel and water pipeline. Other cables and tubes can also be tracked in this area. The pictures are the illustration the theory discussed on utilities as shown in figure A.1.8.

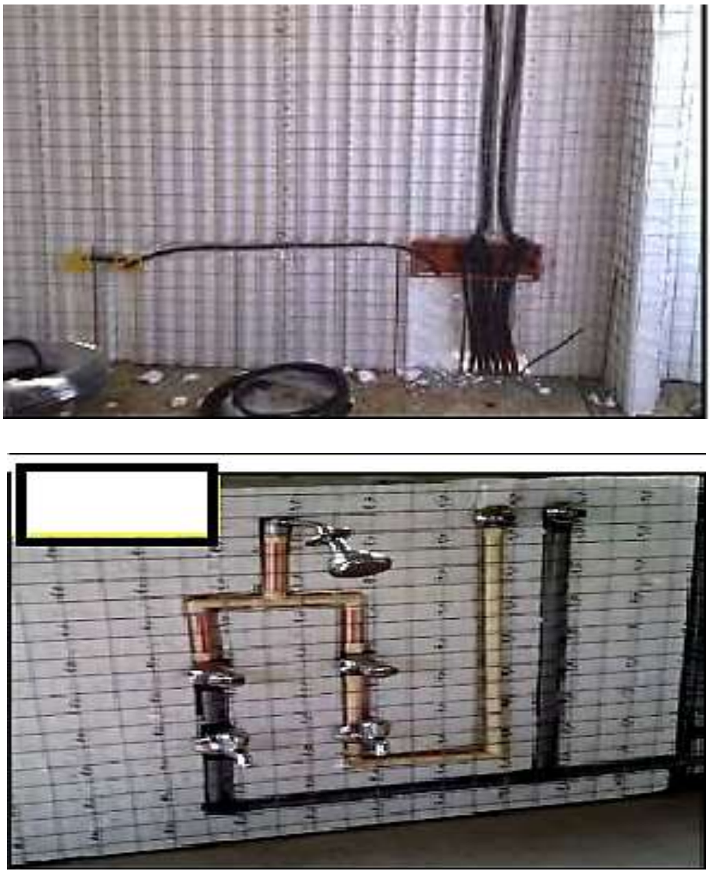

Figure A 1.8. Electrical Conduits and Water Pipeline provisions (EVG)

A.5 – PLASTERING: - Then the plastering is done from both interior and exterior in two casings one of 15mm and second coat of 10mm. These dimensions are the minimum vales used in the coating.

Figure A.1.9. plastering (EVG)

A.6 HOUSE TOP BOARD FIXING: - Housetop boards and the wallboard is installed and edges are joined with an edge joining joint L mesh in corners.

housetop installation is supported for a suitable position.

- All house top boards are mounted & every one wall slab board joint is linked. Housetop boards.it with the roof board.
- Then the parapet board is mounted and linked to slab board.

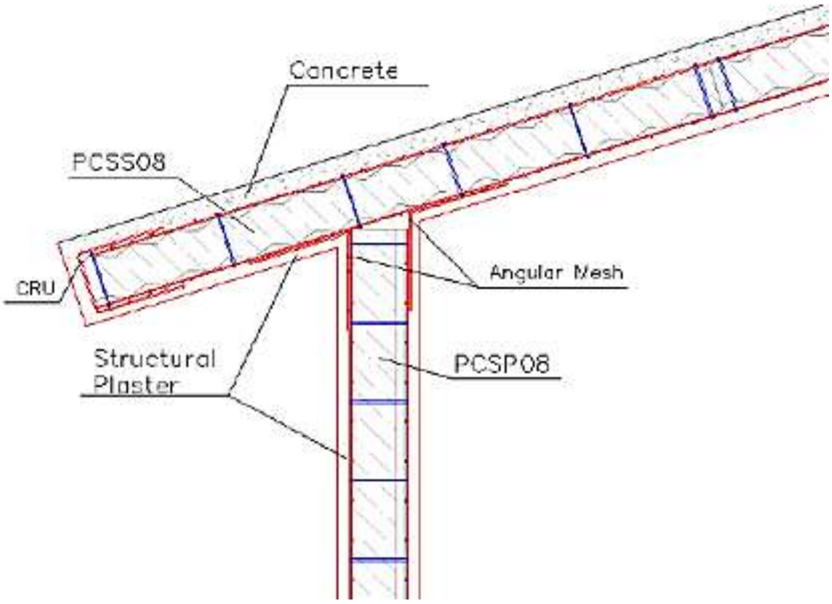

Figure. A.1.10: Roof board setting (BMTPC)

A.7 SHOTCRETING: - • By the help of shotcrete pumps cement matrix is gushed on boards up to a required depth.

•The shotcreting, assistance could also be taken from IS 9012:1978 done in 2 layers.

• The 1st coating is provided to hide the welded-wire material and the 2nd coating is to provide ultimately needed depth.

Figure. A.1.11: Process of shotcreting (BMTPC)