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P - delta Analysis of RCC Framed High Rise Building Equipped with Shear wall and Damper: An Overview of Experimental and Numerical Study

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ABSTRACT
The reinforced concrete buildings are subjected to lateral forcesdue to wind andearthquake and these forces are governing factors specially in highriseand slender structure. Inorder to preventlateralforces, the buildingsare provided with shear walls and dampers as lateral loadresisting members which fundamentally possesses adequatestrength and stiffness. Theimportance of shear wall in reducingthe damage to reinforced concrete buildings iswellknown in the literature.The effect of dampers on structures byapplying to thespecific location of component elements with known damping and stiffnessproperties that can changestiffness. The impact of providing such dampers at precise locationshave been studied. These locations arebetween cut out sections of the wall member and the shear walls near the coupling beams in tallstructures. The response of structure of shear wall strongly depends onthe loading type, sizeand height to width ratioof shear wall, location and size of the openings in theshear wall and ductile detailing and strengthening around the openings of shear walls. The study has been conductedaccording to Indian standard codes. This paperprovides the reviews of the researchworkcarried out through experimentalinvestigation or using analytical solution and numericalmethod. The reviewinvolves the experimental and analyticalinvestigation of shear wall, dampers, influence of wind on building with shear wall.

Keywords: Shear wall, dampers, experimentalinvestigation, numerical modelling, analyticalstudies, p-delta effect,high rise building

1. INTRODUCTION

By 2050, the world's residents will reach 9 billion, 75% of which will be living inmetrocities. The population will reach 1.7billions which will be highest in the world. With speedydevelopment and population densification, townsin the world have witnesseda fastincrease in the number of buildings with height greater than 50-meter, supertallstructures having height greater than 300 meters, and megatallbuilding having greater than 600 metersheight.Site Specificanalysis and designproblems are faced due tall buildingsincluding their low damping, largedead and liveloads, P-Delta effects, higher mode effects. their numerical models consist several thousand degrees of freedom which creates another majorissue. So, as buildings gethigher and slenderer, reducing vibrations under frequent earthquakes forresidentwell-being anddecreasing large forces induced by windforcecrates bigger issues. In regions where earthquakes are regular, structural and non-structuralparts and contents in high rise buildings can suffersignificantdamagedue to seismic forces. Thus, how high buildings will act under natural catastrophes is necessary in findingtotal resilience of cities. [1]

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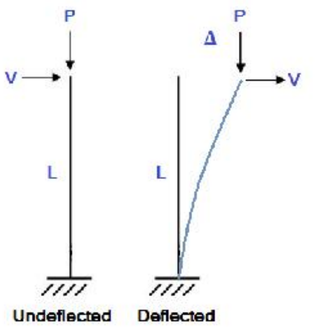

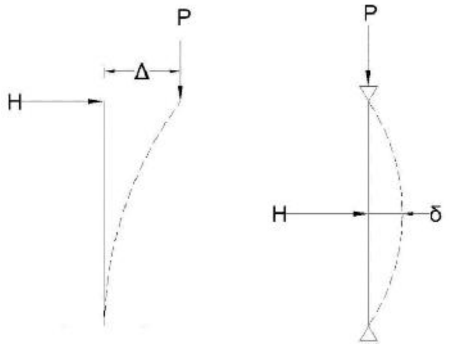

(a) **(b)**

Fig 1 : Deflected shape due to Lateral and Gravity load

Fig 2(a) – Large P-delta effect
Fig 2(b) – SmallP-delta effect

2.1 P- DELTA(Δ)EFFECT ON BUILDING:

When the seismic lateral loading acts on a building,leading to it to deflect, the gravityloading on such laterally deformed structure may cause the lateral displacements toincrease.The second order effect of vertical loads actingupona laterally displaced structure is termed the P-Δ effect, where P is the total vertical load, and **Δ** is the lateraldisplacement relative to the ground.Figure 1 shows the P-**Δ**effect on a SDOF system. The P-**Δ** effect refers to the mass ofthe structure with a weight.P, moving through a displacement**Δ**, causing a moment atthe base ofthe structure. [2]

P-delta effect is the additional destabilizing moments that is produced on a laterallydisplacedbeam-column when a gravity load 'P' acts on the eccentricity 'Δ' created due to therelativedisplacement of the frame elements. This effect can be categorized into two types:

•P-Δ (P-Big delta or Large P-delta), the frame instability effect, has been stateddue to the effects of the vertical loads such as gravity load acting on the laterally displaced structure which is given in Figure 2(a).Wind or earthquake forces (V) trigger the horizontal displacement (Δ) of the structure, while simultaneous action of gravity loads (P) vertically on this displaced structure causes vertical displacement. The secondarymoments are included into the structure equal to the total vertical load P times the structuraldisplacement Δ.[3]

•P-δ (P-small delta or small P-delta), has been referred to the effects of theaxial forcein an individual member subjected tothe deflection amongst its endnodes which is shown in Fig 2-(b). P-δ effect that occur due to the change in member stiffness under the load and additional moment,in this case caused due to the curvature of the member.In practical calculation value of P-δ will be less than that of P-Δ.Load (P) caused due to seismic, wind or gravity forces act on a column that has instigated thedeflection by the connection situations of supported beams. Inducing the moments which arein the member is proportional to the axial load P times the deflection δ. So P-δ is considered to be significant at large displacementvalues in compression members such as columns.The axiallyloaded beams also experience these effects[3].

The deflection at Level x (δ_x) used to compute thedetermined in accordance with the following equation:

$$\delta_x = \frac{C_d \delta_x}{I_e}$$

Where C_d = deflection Amplification Factor

δ_{xe} = Deflection found by Elastic analysis

I_e = Importance Factor

To avoid P-**Δ**effect structural members such as shear walls, composite structures, energy dissipaters are used.

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2.2 SHEARWALLS:

The shear wall is a structural member used to counter moments generated due to lateral load such as wind load, seismic load acting on a structure. Shear walls are used to counter torsional effect caused due to lateral loading or P-Δ effect. Design of shear wall has provided in IS 1893:2016 and IS 13920:2016. All lift lobbies are concrete shear walls. When the moment acting on shear wall is very high then a beam is provided between two shear walls to increase stiffness. That beam is called as coupling beam. Sometimes due to architectural aspects opening are provided in shear wall. In such situations extra reinforcements are provided around opening to avoid failure.

Table 1: Types of Shear walls

Based on Material	1)Steel Plate shear wall 2) Timber Shear wall 3) Reinforced Masonry Shear wall 4) Reinforced Concrete Shear wall
Based on Aspect Ratio (Height to Width Ratio)	1)Squat Shear wall – Aspect ration between 1 and 3 2)Slender Shear wall – Aspect ratio greater than 3
Based on Geometry	1)Rectangular Shear wall 2)Bar Shaped Shear walls 3)Flanged Shape Shear walls 4)Coupled Shear walls 5)Core Shear walls

2.3 DAMPERS

A damper is a device mounted in structures to reduce the amplitude of mechanical vibrations.Basically,dampers are energy dissipaters which absorb energy during earthquake or storm conditions where wind load is maximum. A metallic damper has been used in Taipei 101 which is 509.2 meter in height, one of the tallest building world. The weight of damper is 720 tons and 18 feet in length. Wheneverheavy wind or earthquake's ground motion building starts vibrating at a certain frequency. Damper used in Taipei also vibrates but in opposite direction. This helps in reducing the frequency. A hospital in America used viscous wall damper which saved building from falling during earthquakes.ATC tower in Delhi Airport has installed 50 ton tuned mass damper underneath the ATC floor at 90 meters. The famous hotel in Dubai Burj Al Arab has installed 11 tuned mass dampers to resist the building during earthquakes.

Active dampers need to be connected with energy sources from outside. But passive dampers work on energy collected from lateral loads. There is not any requirement for external power source to work in passive dampers. In catastrophic situations where electric power source may not be available passive dampers are preferred.

Table 2 – Types of Dampers

Active and Semi Active Dampers	Braces	Piezoelectric	Rheological	Tuned Mass	Variable Stiffness
Passive Dampers	Metallic	Viscoelastic	Friction	Viscous	Self-Centering

Dampers can be used for new construction as well as retrofitting and strengthening of existing buildings. Before damper implementation extensive analysis of building should be carried out to determine the location and number of dampers required. Then next step is to select the damper type and size for designing of damper. By varying coefficients and loads the optimum and most economical damper is selected.

3.0 LITERATURE REVIEW

The literature of shear wall and dampers is reviewed in following sub section while giving extra attention to Dampers used as energy dissipaters.The review is conducted as Experimental andAnalytical Investigation.This literature review analyses for a period spanning three decades, 1983to 2017.

3.1 EXPERIMENTAL INVESTIGATION

Timler and Kulak (1983)led a, single-storey steel plate shear wall test. The experiment wasconductedtofind the tension field development in the infill plate, the out–of–plane behaviour of the plate under service load reversals (quasi-wind cyclic loading), andthe ultimate load behaviour of the system. The test was carried by using a pair ofsingle-storey, one-bay, shear wall having pinned joints at the four corners of the structure. The bending strain energy of the columnswasadded to the energy calculation by Timler and Kulak.The new equation of the angle of inclination ofthe tension field:

$$\alpha = \tan^{-1} \sqrt[4]{\frac{1 + \frac{t_p L}{2A_C}}{1 + t_p h \left(\frac{1}{A_b} + \frac{h^3}{3 I_C L}\right)}}$$

Where I_C is the moment of inertia of the boundary column, α is the angle of inclination of tension field,$t_p$is the infill platethickness, Lis the width, his the height of the panel, *Ab* and *Ac* are thecross-sectional area of the beam and an individual column.

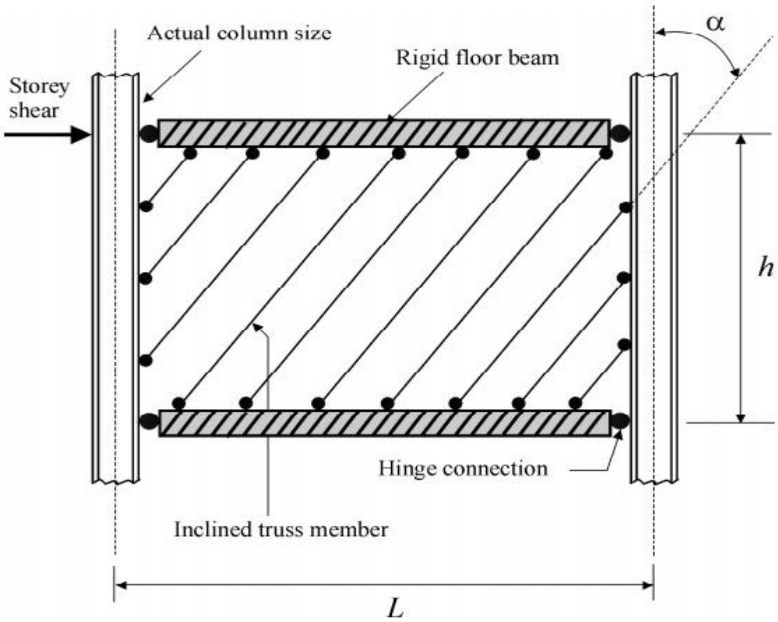

Fig 3Strip Model proposed by Timler and Kulak(1983)

Lin and Kuo (1988) guided an experiment to understand the ultimate strength of shear wall with openings under lateral load. Finite element analysis was conducted to study stress distribution within shear wall before crack and to forecast the ultimate strength of the wall. The results show that the shear strength added by diagonal reinforcement around opening was 40% of yield strength. [4]

Ali and Wight (1991) conducted tests on lightly reinforced barbell-shaped slender walls (3.56 m high and 1.22 m wide) with staggered openings for moderate axial and shear loads. The horizontal and vertical reinforcement in the web portion and boundary element portion in shear walls were0.3% and 3% respectively. The total opening area in the shear walls they considered was 13.4%of the area of shear wall.[5]

Seleemah and Constantinou (1997) investigated the seismic analysis of a model with linear and nonlinear fluid viscous dampers using shake table tests. The model structure was the 0.25-scale three-story steel frame used by Constantinou and Symans (1992) which was repaired. The structure was tested with threedampers: (1) with 2 dampers placed diagonally in the second story; (2) with 2 dampers in both the second and third stories; (3) with 2 dampers in each story.Each nonlinearviscous damper has a coefficient of $C\alpha$ =252 N-(second/mm)and velocity exponent α=0.5. The test results showed that nonlinear dampers generally produced more drift response reduction than linear dampers.[6]

Taylor et al. (1998) conducted the experimental investigations on the response of four storeyed slender shear wall of size (width × height × thickness) 1200 mm × 3600 mm × 100 mm (48 in × 144 in × 4 in) with the base opening of sizes 300 mm × 675 mm (12 in x 27 in) and 225 mm × 500 mm (9 in × 20 in). Experimental outcomes show that properly reinforced slender shear wallshaving openings at the base exhibit stable structural behavior and significant ductility.[7]

Lubell et al. (2000) conducted experiment for thin steel plate shearwall (SPSW). The objective of this experiment was to evaluate the applicability of thin plate SPSW for mid to high-rise buildingbecause the infill plate thickness requirement is very small compared to available one. So, two single (SPSW1, SPSW2) and one multi-storey (SPSW4) test specimen were designed for Vancouver region. The one storey test samples were one-quarter scale. Similar width and height dimensions of 900mm were considered for each test specimen. Besides, SPSW1 specimen consisted of same beam column size of S75X8, however for the SPSW2 specimen, another S75x8 beam was added to the top beam. On the other hand, for the four storey test specimen SPSW4, a deep beam of size S200x34 was used on the top floor. For all the test specimens hot rolled infill plate of 1.5mm thickness was used. Even though no external gravity load was applied for the SPSW1 and SPSW2 but the SPSW4 specimen, an amount of 13.5KN gravity load had been applied on each floor. Well-defined hysteric loops along with excellent initial stiffness were found from the cyclic test but not expected energy dissipation for the selected SPSWs. While testing SPSW4 specimen the columns yielded before the inelastic action of the plate, however for SPSW1 and SPSW2 specimens, infill plate yielded prior to yielding of beam and column. He concluded that

1) Stiffness and capacity of SPSW significantly increased when top beam can offer better anchorage for the tension field developed in the infill plate.
2) Insufficient column flexural stiffness can produce significant “pull-in” in the column and undesirable yielding sequence which can create global instability of the system
3) Due to the high axial loads and moments in the columns, the yielding sequence can be altered. It also indicated that the behavior of a single isolated SPSW is different from a multistory SPSW.[8]

Lee *et al.* (2007) employed the Real-Time Hybrid Simulation (RTHS) method to fins the performance of Tuned Liquid Damper (TLD). They tested the TLD as experimental substructure and structural computer model was created by using SAP2000 software. Results were compared from those of a shake table test. They indicated that the RTHS method can evaluate the behaviourof TLD-structure system accurately.[9]

Gulecand Whittaker (2009)examined the mechanisms of failure of critical squat reinforced concrete shear walls and a database with experimental data obtained from 434 tests was assembled. Empirical equations were established for maximum shear strength for rectangular walls and walls having boundary elements. Moreover, modeling that was most important in predicting response were analyzed and recommendations for finite element analysis model were made.[10]

Ki-Pyo You and Young-Moon Kim (2013) studied the properties of circular and rectangular tuned mass damper with experimental setup. Authors used two liquid tanks of circular and rectangular shape and attached displacement sensors inside the tanks and was connected with computer. Authors concluded that base shear due to water splashing was 10-20% higher inrectangular tank than circular tank. Over natural frequency0.55Hz, rectangular tank should bepreferred over circular tank whereas when frequency is lower i.e. around 0.44Hz, circular tank ismore effective than rectangular tank. [11]

Chandurkar (2013) compared seismic analysis of G+10 building with shear wall and building without shear wall. 1st model was without shear wall, 2nd model was with shear wall along horizontal sides and 3rd and 4th model was having shear wall along corner.4th model had shear wall of different size that of model 3. Storey drift and displacement was found along different zones according to Indian codes. Quantity and cost of concrete was maximum in model 3 where as steel was used maximum in model 1. The percentage of steel in column was maximum in model 2 but maximum cost of building in zone V compared to other zones. [12]

Bhattacharya et al (2014)performed experimental and analytical analysis to findpressuredistribution on 'E' plan shape building with shear wall under wind loads with wind angleschanging from0°- 180°at an interval of 30°. Experiments were done in open circuit boundarylayer wind tunneland analytical study was done by CFD technique using ANSYS CFXsoftware. He used a modelscale of 1:300. Model used is shown in Image.The authors concluded that:

(1) Maximum positive mean pressure coefficient is found on face E for 180° wind angleand maximum negative mean pressure coefficient is observed on face A for 90° wind angle.
(2) Pressure coefficient from face A to face I changes from negative to positive with equalforces implicating almost zero mean pressure coefficient on these faces.
(3) Variations of pressure coefficient on faces A, B and D are almost equal for 0°, 30° and 60°wind angles through the vertical centerline. [13]

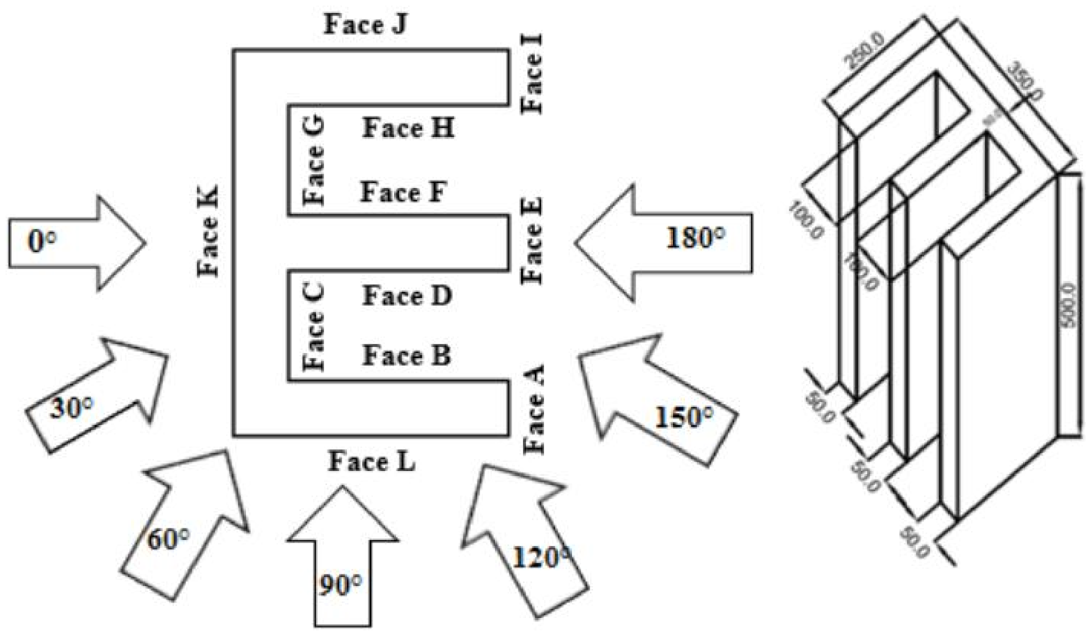

Fig 3: Wind effect on EShaped Building with Shear wall

Teruna and Majid (2015) studied energy absorption capacities using hysteretic steel damperusing experimental setup. The authors used equal thickness height and width of damper but changed the shape of their sides. DHSD1 was straight in sides, DHSD2 had concave shaped sides, DHSD3 and DHSD4 had convex shaped sides but thickness was considered as 26mm and 30 mm.The specimens were attached to T beam and strong base frame. The cyclic loading was applied to the specimen. Authors concluded that DHSD4 showed more than 50% hysteretic damping ratio inmaximum displacement condition. [14]

Lu and Huang (2017) studied mechanism of energy dissipation of particle damper. Anexperimental setup of 1:200 scale of 76floor building in Australia is considered. Four materials i.e. Tungsten carbide, Steel, Copper and lead wereconsidered for damping. Light wooden box containing 2 layers of particles were considered as setup for particle damper. As damper is to be suspended the reading can be taken from pendulum action. Authors concluded that steel provided least damping ratio of 2.74%, while Tungsten carbide provided maximum damping ratio of 5.98%.followed by Copper (5.26%) and Lead (3.45%). [15]

3.2 ANALYTICAL LITERATURE RIVIEW:

Adebar & Ibrahim (2002) proposed a tri-linear bending moment-curvature model for the nonlinear static analysis of concrete walls by accounting the effect of cracking on the flexural stiffness of wall. The model accounts for concrete tension-stiffening after cracking. The linear elastic response was replaced by two linear segments. The slope of the first linear segment wasassumed to be equal to the uncracked-section stiffness, while the slope of the second straight-line segment was assumed to be equal to the fully cracked section stiffness. The proposed model wasvalidated with experiment conducted on ¼th scale model of 73.2 m high prototype wall.[16]

Berman and Bruneau (2003)used the concept of plastic analysis and the strip model, and derived equations to find the ultimate strength of single and multistorey SPSWs with simple and rigid beam-to-column connections. For a singlestorey SPSW with simple beam-to-column connections, theassumed collapse mechanism gives a storey shear strength, V_{yp} identical to theexpression given in CAN/CSA S16-01 for the probable storey shear.

$$V_{yp} = 0.5\, F_{yp}\, t_p\, L \sin 2\alpha$$

where F_{yp} is the yield strength of the infill plate and all other parameters have been defined earlier. Equation was modified for a frame with rigid beamtocolumn connections by adding the components of internal work from plasticmoments in the columns and (or) beams.To calculate ultimate strengths of multi-storey SPSWs, two types of failuremechanism, were assumed: (1) soft storey mechanism, and(2) yielding of all infill plates and plastic hinging at the ends of all beams (exceptfor the top and bottom storey where plastic hinging is also allowed at thecolumns) formed simultaneously. These two mechanisms help the design engineerto estimate the ultimate strength of single or multi-storey SPSW and investigatethe possibility of soft storey mechanisms.[17]Berman and Bruneau (2003) also looked at the design of SPSWs using theprovisions of CAN/CSA S16-01. It was observed that for calculating infill platethickness, the storey shear*Vs* found from the equivalent lateral force method,should be multiplied by a system overstrength factor, **Ω**, between 1.1 to 1.5.Thus, the minimum infill plate thickness required to resist storey shear is given by the following equation as:

$$t = \frac{2V_S\Omega}{F_Y L \sin 2\alpha}$$

where*Fy* is the nominal yield strength of the infill plate.[18]

Levy and Lavan (2009) performed quantitative analysis concluding that active controltechniques for optimizing damper placement are less effective than passive controltechniques. Active control damper was not as effective as passive dampers for reducing inter-storey drifts thanfullystressed analysis/redesign methods using deterministic (time history ground motionrecords) or stochastic ground motions. This is attributed to the standard activecontrol approach of considering “an integral on the sum of a quadratic form of the statevariables,” as opposed to constraining the maximum performance objective (Levy & Lavan2009). Also,limitation of this methodis that the the knowledge of control theory must been known prior knowledge ofactive control theory to apply the technique to theoptimal placement of dampers. [19]

Dalui et al (2014)studied the difference in stress distribution on different faces of a ‘+’ plan shape tall building with shear wall for wind angles 0°and 45°. Along with experimental study,authors alsocalculated the flow pattern around the model using ANSYS CFD technique.Plan of thebuilding is shownin Fig 4. The experimental was conducted in type 2 terrain and according IS 875-part III loading was done.A total 396 stress points were located at nine different heights. Turbulence intensity was considered to be 10%. In order to assess the acceptability of the code, numerical analysis on a square plan shape model is carried out and theresults obtained are compared with Indian Standard Code.According to their results:

(1) Faces B1 and B2 experience positive pressure for 0°wind angles due to interferenceeffect offaces C1 and C2.
(2) An increase in magnitude of pressure coefficient is observed for 45° as compared to 0°wind angle for faces B2 and C2.

(3) Pressure coefficient changed from positive in case of 0° wind angle to negative in case of 45°wind angles on faces A, B1 and C1.
(4) Faces E1, F1 and G have same pressure coefficient values for both wind angles.
(5) Pressure coefficient decreases with change in faces. The maximum reduction was observed on face A. [20]

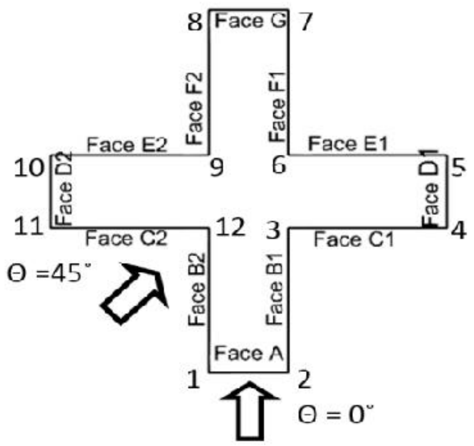

Fig 4: Wind Effect on Plus Shaped Building with Shear wall

Ahlawat (2015)carried out wind tunnel tests on 'T' plan shape and 'Y' plan shape buildings with shear wall to evaluate the wind loads and wind pressure distribution for isolated case andinterference case in different wind angles. In isolated case, the author has taken 5 wind angles i.e. 0°, 45°, 90°, 135° and 180° for 'T' shape and in interference case, 3 conditions i.e.spacing = 0, 50and 100 mm for 0° and 180° angles are considered.According to his results:

(1) Wind flow pattern is greatly affected by the presence of other buildings and it depends on the direction of wind, spacing between the buildings and the geometric shape of the buildings.
(2) Base shear on the building gets reduced due to shielding and it increases as the spacingincreases.
(3) At the edges and corners of walls, suction due to wind can increase hugely due to interfering building.[21]

Shedbale Nikhil (2017) studied influence of aspect ratio on placement of Visco-Elastic damper. For a model Height to Width Ratio is considered as 1 and for another model the ratio is considered as 2. The analysis and design has been carried out on ETABS software. Various locations and floors has been considered for damper placement. Maximum Deflection and Story Drift with different damper location has been calculated. The author concluded that location of damper and aspect ratio decreases the structural response of building. Proper selection of damper location and aspect ratio can decrease the time period of structures. The Visco-Elastic damper was more effective for the model with aspect ratio as 1.[22]

4.0 CONCLUSION:

An effort has been made to study the experimental and analytical research for shear wall and dampers study. The P-delta effect is a second-order effect that occurs on any laterally deformedstructure. There are many methods currently available by which to measure it; however,none of them take the influence of vertical load distribution into account. In real worldsituations, it is extremely hard to control vertical load distributions so that to make themideally symmetrical, and it is this situation that makes this research meaningful. In thisstudy, the finite element nonlinear static analysis is used to compare with the currentlyused linear analysis approach for the lateral displacements of a structure.

Shear wall and damper are effective in reducing the lateral and gravity forces in the building. Location of Shear wall and damper affect the torsional effect of building and economical design will be possible with correct analysis and choice of damper.Location and quantity of dampers can be found out by in depth analysis of building.

The opening of shear wall will cause extra tension around opening and will have to provide extra reinforcement around openings. The size, location and height to width ratio of opening in shear wall affect the displacement of the building. Coupling beam between two shear provides extra stiffness and helps in providing openings.

Still there is need for more economical and effective experimental and analytical methods so that better results can be achieved. There is scope of study in comparing different dampers and shear walls for exact location. There is not any study carried out with combination of shear wall anddamper.

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