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A Study on Development of Direct Displacement Based Seismic Design of Reinforced Concrete Frame Building

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Abstract: The assessment of reinforced concrete building frame structures are designed according to the Direct Displacement– Based Design, recently proposed as model code. The traditional Force-based Design approach cannot provide the appropriate means for implementing the concepts of performance based design. It is widely understood that it is not the force, but displacement, which can be directly related to damage. Performance levels, indeed, are described in terms of displacements, as damage is better correlated to displacements rather than forces. As a consequence, new design approaches, Direct Displacement – Based Design (DDBD) , firstly proposed by Priestley (1993).DDBD is based on the observation, that damage is directly related to strain (structural effects) and drift (non-structural effects) and even both can be integrated to obtain displacements. In the present work, a 9-storey frame building is characterized and designed respectively according to DDBD and to the traditional force-based design method (FBD), as proposed in Euro code 8 (EC8) and IS1893:2002 is carried out and the differences are outlined. The base shear force is an appraisal of the maximum estimated total lateral force that may possibly come about due to seismic ground motion at the base of a structure. In the following paper, it confirms that only the shortened method based on equilibrium considerations will be defined.

Keywords: Peak Ground Acceleration (PGA), Direct Displacement Based Design (DDBD), Force Based Design (FBD), Stadd Pro Analysis, Design Displacements And Target Displacements, Effective Stiffness, Base Shear And Storey Drift.

I. INTRODUCTION

EARTHQUAKE – It is basically represented as shaking of an earth surface. The relative displacement known as slip because of rupture it may reach several meters over a surface of the terrain and it may exceed 10,000 km^2.This slip prompts seismic waves which propagatein to the soil in turn vibration of the ground occurs in all ways. The design principle is stated performance objectives when the structure is imperiled to specified levels of seismic design.Since the Northridge earthquakeat the end of the 20thcentury, it can be treated as an eye-opener for the use of PBSD. Current seismic codes are based on Forced Based Design (FBD). Current force-based design is substantially enhanced associated with procedures used in earlier years; there are many essential problems with the procedure, particularly when smeared to reinforced concrete structures. DDBD is comprehensively developed with the aim to correct insufficiencies in the analysis and design made consequently to force based design techniques. The essential problem of force based design, mainly when applied to concrete or masonry structures, is the choice of suitable member stiffness. The following terms were discussed briefly in this project

- Ground motion
- Characteristics of ground motion
- Design approach
  1. Force based design approach
  2. Drawbacks of forced –based design method
- Direct displacement- based design approach
- Effects of earthquakes

II. SEISMIC HAZARD ANALYSIS

Ground motions are mainly characterized by, the intensity, the frequency content and the duration of the ground motion. Factors that are equally as important include the energy release mechanisms in the vicinity of the hypocentre and along the fault interfaces, the geology and any variations in geology along the energy transmission paths, the epicentre distance, the focal depth, the magnitude and the local soil conditions at the recording station.

A. Seismic hazard analysis of India

The Indian subcontinent is a region that is prone to earthquakes. Between the years 1990 to 2006, more than 23,000 lives were lost due to six major earthquakes in India. The most notable being the Delhi earthquake, 2001 Bhuj earthquake and the 2005 Kashmir earthquake. According to the code IS-1893 (Part I):2002, the country is divided into four seismic zones – Zones II (MSK intensity VI), Zone III (MSK intensity VII), Zone IV(MSK VIII) and Zone V (MSK intensity IX or more) each associated with a seismic zoning factor (Z, effective peak ground acceleration) based on anticipated intensity of shaking as shown in Table 4.1. The zoning map is based on expected maximum seismic intensity on the Modified Mercalli scale.

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Fig1. Seismic hazard analysis methods.

Seismic hazard analysis involves the quantitative estimation of ground shaking hazards at a particular area. The most important factors affecting seismic hazard at a location are:

1. Earthquake magnitude
2. The source-to-site distance
3. Earthquake rate of occurrence (return period)
4. Duration of ground shaking

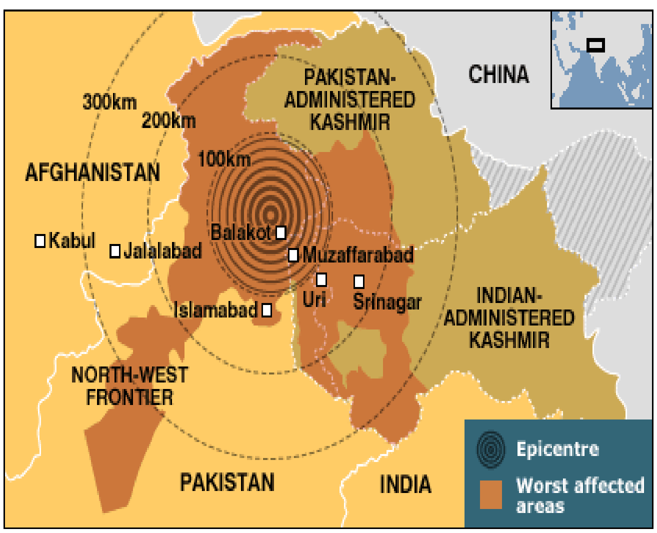

Fig2. Worst affected areas of earthquake.

B. Representations of seismic hazard

Seismic hazard can be represented in different ways but most frequently in terms of values or probability distributions of accelerations, velocities, or Displacements of either bedrock or the ground surface, Ground acceleration, velocity and displacement are related among them because integration or differentiation in time of one of them produces another. Time histories of ground motions are often used in practice for non-linear analyses when damage caused by ground shaking can accumulate in time.

Deterministic seismic hazard analysis (dsha)

Originated from nuclear power industry applications, Deterministic Seismic Hazard Analysis was the earliest approach taken to seismic hazard analysis. This analysis is still used for some significant structures such as-

- Nuclear power plants
- Large bridges
- Large dams
- Containment facilities containing hazardous waste
- Check for probabilistic analyses.

Four primary steps are generally involved in Deterministic Seismic Hazard Analysis-

- Identification and characterization of all sources
- Selection of source-site distance parameter
- Selection of "controlling earthquake".
- Definition of hazard using controlling earthquake.

Probabilistic seismic hazard analysis (PSHA)

Probabilistic seismic hazard analysis (PSHA) is the most widely used approach for the determination of seismic design loads for engineering structures. The use of probabilistic concept has allowed uncertainties in the size, location, and rate of recurrence of earthquakes and in the variation of ground motion characteristics with earthquake size and location to be explicitly considered for the evaluation of seismic hazard.

Applicability of dsha and psha

DSHA involve the assumption of some scenario and the occurrence of an earthquake of a particular size at a particular location for which ground motion characteristics are determined. DSHA provides a straight forward framework for evaluation of most severe ground motions when it is applied to structures, the failure of which could have catastrophic consequences, such as large dams and nuclear power plants. However, it provides no information on the chances of occurrence of the controlling earthquake, the likelihood of it occurring where it is assumed to occur, the level of shaking that might be expected during a finite period of time such as the useful lifetime of a particular structure or facility, or the effects of uncertainties in the various steps required to compute the resulting ground motion characteristics

Uniform Hazard Spectrum (UHS)

A prior probabilistic hazard analysis is necessary for the derivation of the uniform hazard spectra (UHS). The basic steps followed in the analysis are as follows. At the start of analysis, seism tectonic information is required to define seismic source zones. For the configuration of these seismic zones, a number of alternative hypotheses identifying these configurations are formulated.

III. STRUCTURAL MODELLING OF FBD

A. Design principles of force based design

Assumptions:

- An earthquake causes impulsive ground motions, which are complex and irregular in character, changing in period and amplitude each lasting for a small duration. Therefore, the resonance of the type as a visualized under steady state sinusoidal excitations, will not occur as it would need time to build up such amplitudes.

- An earthquake is not likely to occur simultaneously with wind or maximum flood or maximum sea waves.
- The value of elastic modulus of materials, wherever required, may be taken as static analysis unless a more definite value is available for use in such condition.

B. Analysis of a 9-storey reinforced concrete frame building

From the main menu(general (construct a frame)

Supports:

Support – whole structure →create →fixed →add →select support→ select elevation view →select below base node points →assigned to selected nodes →assign →close .

Properties:

From the main menu (General (properties –whole structure → section → define → property→ select rectangle

Rectangle 1: YD= 0.75 metres

ZD= 0.50 metres → add →close →define →property → select rectangle

Rectangle 2 : YD= 0.35

ZD= 0.25 →add→close.

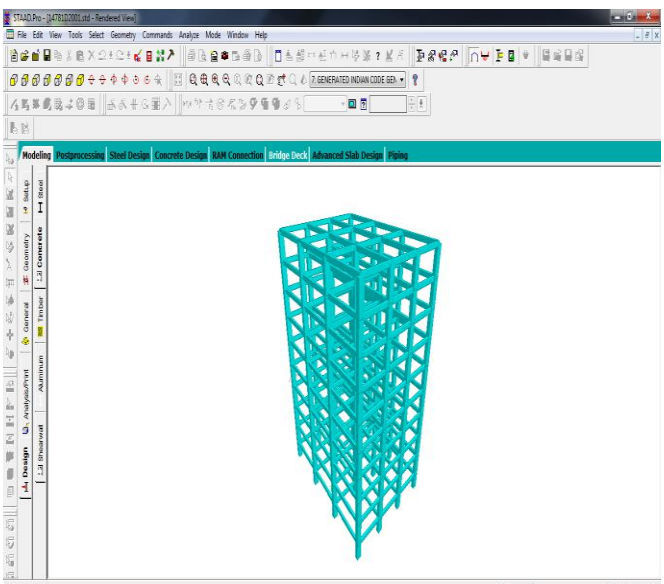

Fig3. 3-D View of Whole Structure.

Loads and definitions:

Vertical gravity loads ------ Dead load, Live load} primary loads

Horizontal loads ------ Wind load, Earthquake load

1. Dead load |IS 875 part -1|
2. Live load|IS 875 part -2|
3. Wind loads |IS 875 part -3|
4. Seismic loads (IS 1893:2002)

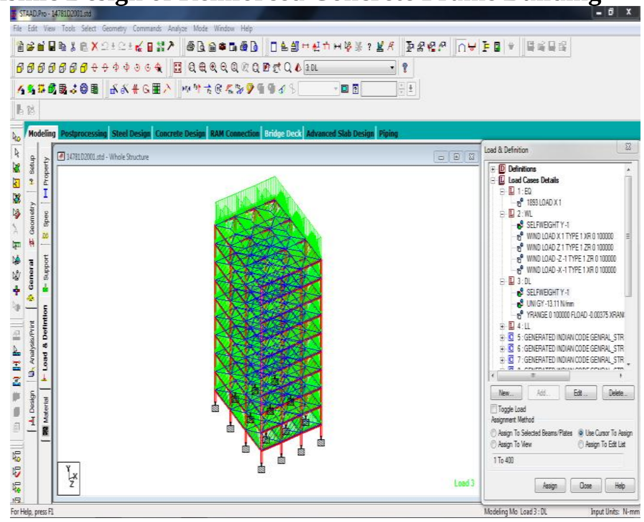

Fig4. Assigning of loads and definitions.

C. Wind definition

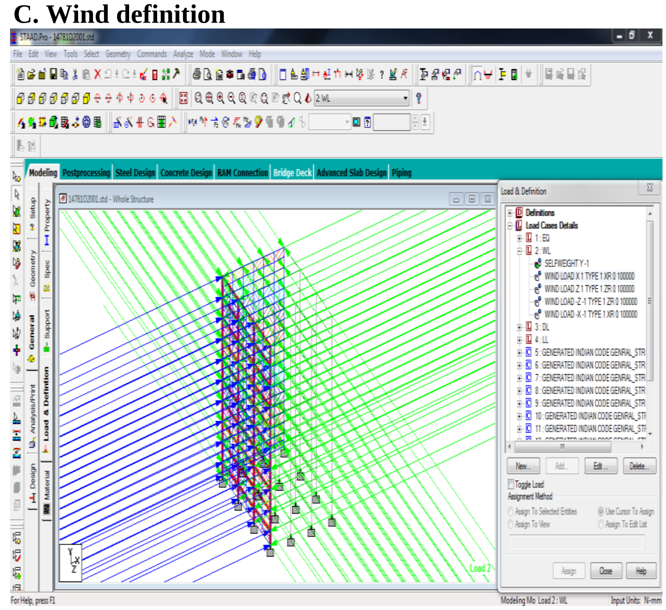

Fig5. Wind Pressure in X-direction.

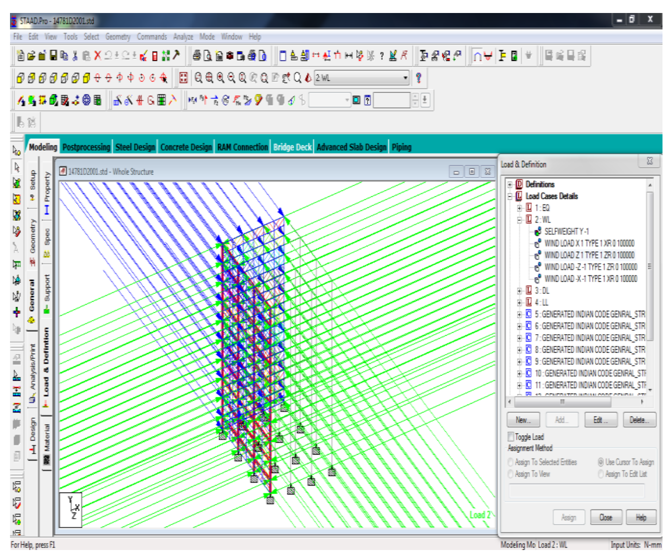

Fig6. Wind Pressure in Z-direction.

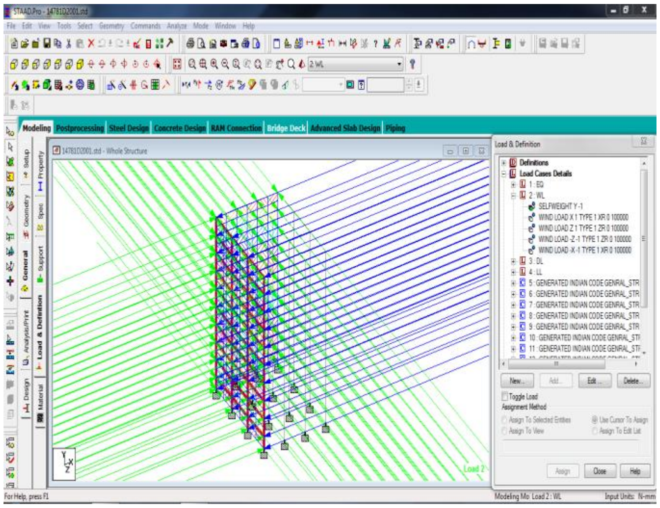

Fig7. Wind Pressure in –ve X-direction.

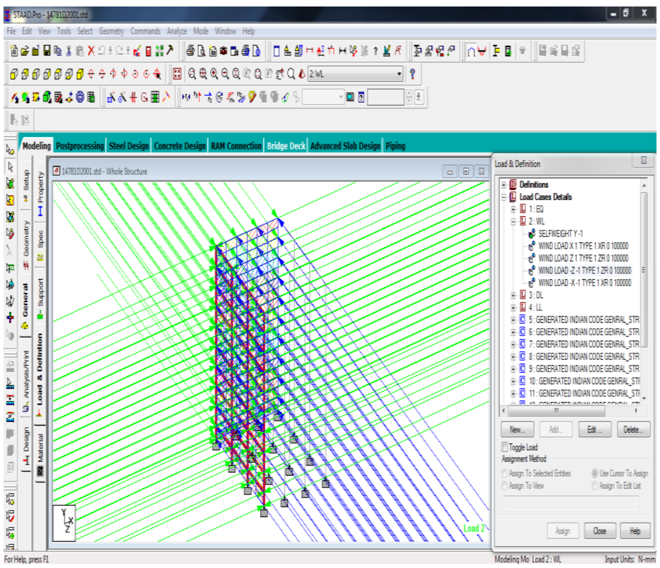

Fig8. Wind Pressure in –ve Z-direction.

Design:

From main menu →General→Design→concrete→change units N-mm→

Select code IS 456 →define parameters→select grade FC=25 →add→FYMAIN Fy=415→add→

FYSEC---Fysec=415→add→clearcover→Beams =25mm → add→columns=40mm→add→

MAXMAIN=32mm→add→MINMAIN=12mm→add→MAXSEC=12mm→add→

MINSEC=8mm→add→Assign to view→Assign.

Select command →Design of Beam→add→Design of column →add→From main menu→select→Beams parallel to X-Axis→Assign to selected beams →Assign →select→ beams parallel to Z-Axis →Assign to selected beams →Assign→selectbeams parallel to Y-Axis→Assign to selected beams→Assign→close→Commands →Analysis → perform analysis→O.K.→From main menu →Analyze→ Run Analysis→View output file →close.

Design Results:

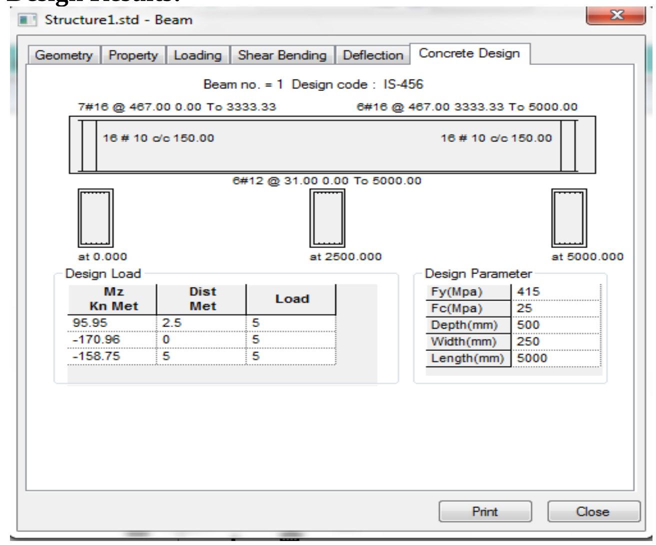

Fig9. Concrete design of the exposed beam 1.

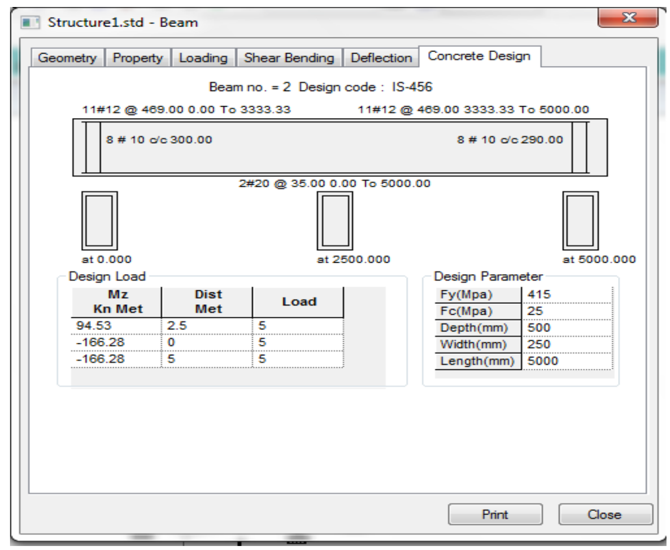

Fig10. Concrete design of the exposed beam 2.

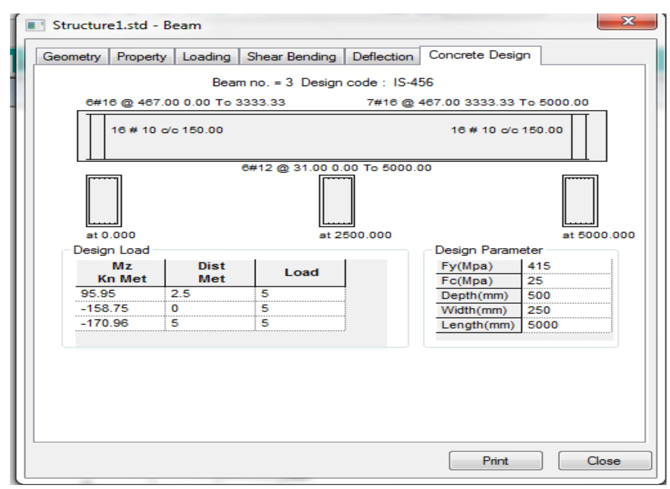

Fig11. Concrete design of the exposed beam3.

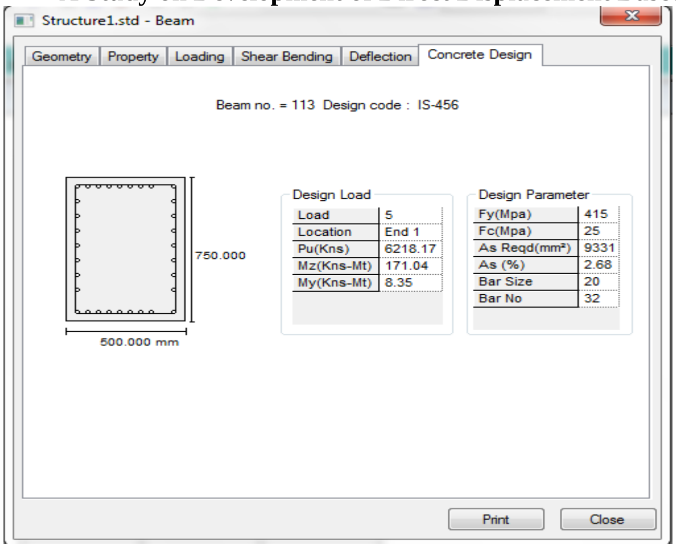

Fig12. Concrete design of the exposed column 113.

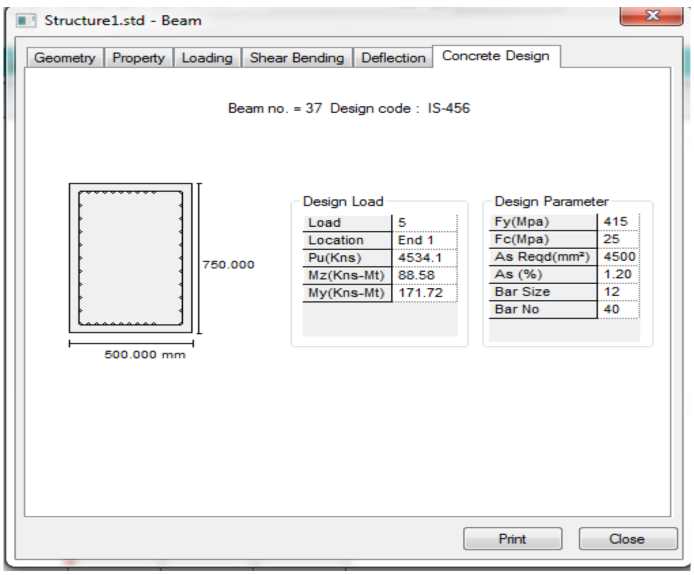

Fig13. concrete design of the exposed column 37

IV. DISPLACEMENT METHOD ANALYSIS & DESIGN PROGRESSION FOR DDBD

A. Design assumptions

- Plane frames with three spans of 5m length each with 6 stores are considered.
- Each group comprises of a vertically regular structure(h=3m).
- Assumed mechanical properties of materials are fck=25 mpa and fy =500 mpa.
- In addition to the self-weight of the beams and the slab, a distributed dead load of 1.5 KN/m2 due to floor finishing and partitions is considered, as well as an imposed live load with a nominal value of 2 KN/m2.
- Slab thickness is equal to 0.15 m and its contribution to the structural response was taken in to account by considering an effective beam width according to Euro code 8(1998).
- Column cross sections were defined in order to limit the normalized axial force (EC8, 1998).
- Dimensions of a beam width equal to 25 cm and depth=50cm.
- In order to simplify the procedure, equal dimensions were considered for external and internal columns without variation inheight.
- Ground acceleration ag used in the definition of the response spectrum is 0.5g.
- Damped displacement spectrum = 5%.
- Zone factor =0.24(for Delhi zone IV).
- Corner Period = 4.0 seconds.
- Overall drift limit equal to 2.5 %.
- Reinforcement schemes have been selected and the criteria for ductile behavior of concrete sections defined in Euro code 8.

B. Base Shear Calculations

STEP 1: The design storey displacements Δi are found using the shape vector δi defined and scaled with respect to the critical storey displacement Δc and to the corresponding mode shape at the critical storey level δc.

STEP 2: Estimate the level of equivalent viscous Damping ξ eq. The equivalent viscous damping can be obtained by one of the equations proposed in the technical literature (Priestley et al, 2007). To obtain the equivalent viscous damping, the displacement ductility μ must be known. The displacement ductility is the ratio between the design displacement and the yield displacement Δy.

STEP 3: Determination of the effective period Te of the SDOF structure at peak displacement response by using the design displacement defined in step 1 and design displacement response spectrum corresponding to the damping level estimated in step 2 ξ_{eq} means entering the design displacement of the substitute SDOF structure Δ_d and determining the effective period T_e. According to Model code for structures that have a design displacement Δd greater than the corner displacement, the effective period, Te is obtained by:

$$\text{Effective period, } T_e = \Delta_d / \Delta_{\xi} \, T_D$$

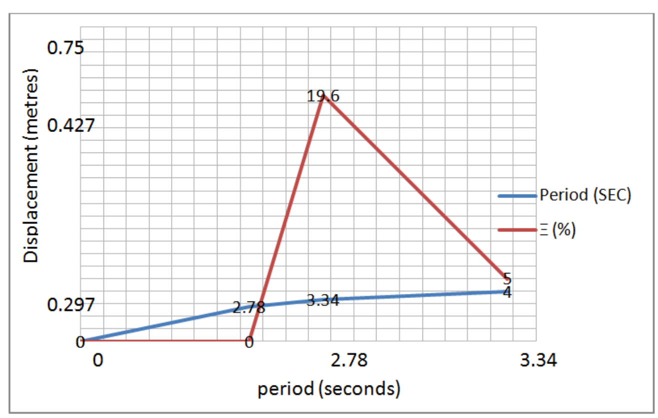

Fig14. Graph between Displacement Vs period.

STEP 4: The effective stiffness Ke of the substitute structure derived from its effective mass Me and effective period Te, and the maximum value Ke, max, are given as:

$$K_e = 4\Pi^2 m_e / T_e^2$$

STEP 5:

Vertical Distribution of Base shear: since the building has only 9 storeys and is rather stiff, it is unlikely that higher mode effects will influence the ductility demands significantly in the upper floors. As a consequence the base shear is distributed to the floor levels and also 10 % base shear additionally allocated to the roof levels.

STEP 6: Assessment of Moment Capacities at Potential hinge Location. To this purpose, two different methods of analysis can be used according Priestley; one is based on relative stiffness members while the other is a simplified method on equilibrium considerations (statically admissible distribution of internal forces).

STEP 7: Shear Force and Overturning Moments

For reinforced concrete structures P-Δ effects should be considered if the stability index □Δ is greater than 0.10, with a maximum value of 0.33. The structural stability index compares the magnitude of theP-Δ effect at expected maximum displacement (Δ_{max}) to the design base moment capacity of the structure (M_D). P is the total gravity expected at the time of earthquake. The structural stability index is given by

$$\square_\Delta = P\Delta_{max} / M_D$$

STEP 8: Check of P-Δ effects

For reinforced concrete structures P-Δ effects should be considered if the stability index □Δ is greater than 0.10, with a maximum value of 0.33. P is the total gravity expected at the time of the earthquake. The structural stability index is given by

□Δ=PΔmax/MD	□Δ=PΔmax/MD
P = (5 *400 +320) * 9.8	=22700*0.297/2*13058.1
= 22700 KN	= 0.258 > 0.1

C. Beam Moments And Column Moments

- The lateral seismic forces Fi produce axial forces (compression or tension) and column base moments (Mc) in each column. The seismic beam shears (Vbi) are derived from seismic axial forces induced in each of the columns.
- Knowing the beam moments, the column moments can be obtained directly by equilibrium considerations: the total storey shear force is shared between the columns.
- Keeping in mind that structural analysis based on equilibriumconsiderations is actually an approximation of the real distribution; the designer gets some freedom in choosing the moment capacities at the column – base of the first floor, provided the equilibrium is maintained between internal and external forces.
- To obtain the moments in the whole columns, the procedure must then be continued with consideration of equilibrium at the node of level 2 and successively to the top level is reached.

V. RESULTS AND DISCUSSION

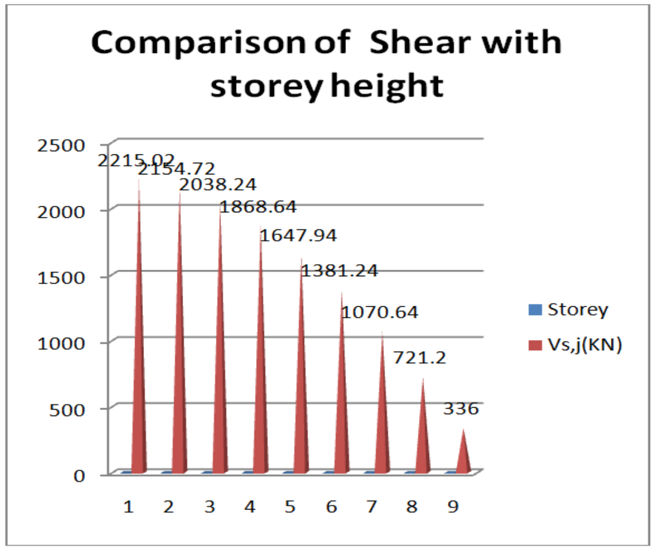

Fig15. Comparison of storey height with shear force.

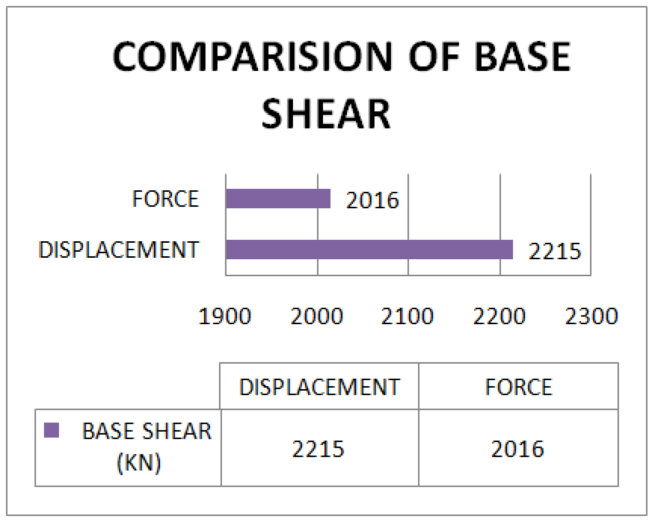

Fig16. Comparison of Base shear.

VI. CONCLUSION AND FUTURE SCOPE

A. From analysis and design results of this research the following conclusions can be derived:

Aimed at low values of seismic intensity less than 0.5g for buildings with number of storeys additional than 8-storeys the base shear known by FBD for loads is higher than the base shear given by DDBDusing the Euro code 8. The proportion between two forces is 0.1 at ground acceleration 0.05g, whereas this ratio increases to 1.1 at ground acceleration 0.5g. For values of ground acceleration equivalents to or more than 0.5g, buildings having more than 8 storeys, it is found that the base shear by DDBD is higher than the base shear by FBD. It can therefore be inferred that the displaced shape by the DDBD procedure is the most conservative as it gives the largest base shear force. The base shear ratio is 1.1 at ground acceleration 0.5g,so it is mentioned to design the building on the largest worth of the base shear to ensure the welfare of tall buildings. The top and bottom reinforcement is provided for each beam and column and the necessary area for providing reinforcement is analyzed and designed over and done withstaddpro analysis. The number of bars required for providing reinforcement is calculated for columns and intended for beams through the design results. By providing the designed reinforcement for the projected structure in this paper, it can withhold the structural damages that arise in seismic activity.

B. Future scope of research

Although the force-based capacity design approach is able to assure life safety, it is unable to provide the designer, the expected degree of damage that will be sustained in various parts of the structure. A displacement –based design displays a means of identifying increasing levels of damage up until the point of structural collapse. In other words, the engineer is now able to manage the seismic risk by balancing the results of the expected outcome in terms of damage with the cost of providing the structure. Although displacement-based shows good results and elements of this are now being used in certain contemporary codes, and established as a full performance-based design approach for complex structures such as multi-storey buildings and large bridge structures. Research still needs to be conducted on the full generalization of displacement –based design approach. This is particularly necessary for structures that may be irregular (structures with torsion or strength eccentricities), structures with significant higher mode effects (tall buildings and long bridges), and structures with a mixture of materials and elements in their construction.

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