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Structural Performance and Development of a Hybrid Coupling beam

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Abstract: *A coupling beam is a structural component used to connect two adjacent shear walls or structural cores. Commonly implemented in high-rise buildings subjected to significant lateral forces like wind and earthquakes. Coupling beams improve the overall stiffness and strength of the structure. By linking shear walls, they enable coordinated resistance to lateral loads, reducing shear deformation between the walls and enhancing seismic performance.*
This paper investigates the behavior of various replaceable steel coupling beams under cyclic loading. Five different models were analyzed, in which various types of beam-to- link connections were adopted, including Stiffeners in Coupling beam, End plate Connection, Splice plate Connection, Bolted web connection and thin plate on web. The findings indicate that, damage in these beams is primarily concentrated on the center of the shear link, leaving the integrity of the shear wall structure largely unaffected. An analytical investigation was conducted to investigate the Load carrying capacity, Load- displacement curve, and Energy dissipation of Steel Coupling Beams

Key Word: *SPRCB, Cyclic Loading Protocol, FEM.*

I.INTRODUCTION

Shear walls are extensively used in high-rise buildings due to their ability to provide significant lateral stiffness and energy dissipation. In combination with frame systems, they effectively minimize sway under lateral loads. Coupled shear wall structures are considered economical up to 30-40 story range. By carrying substantial lateral and gravity loads, shear walls help to reduce the structural demand on columns and beams. Their inclusion enhances overall stability and mitigates the risk of failure during seismic events by limiting excessive deformation. Moreover, shear walls play a critical role in the load transfer mechanism, ensuring that forces are safely directed to the foundation. A coupling beam is a structural element that connects two shear walls or structural cores in a building. These beams are typically used in high-rise buildings where lateral forces such as wind or seismic loads are significant. Coupling beams are typically added to a structure to improve its lateral force resistance. They bridge two separate, independent items together to add stiffness to the overall system. They are usually short and thick, similar to deep beams. As a result, the coupling beams are subjected to shear loads. The coupling beams can improve the lateral resistance and enhance the structure's integrity and dissipate seismic energy by yielding under a severe earthquake and then reduce its seismic response. At present, most coupling beams are made of reinforced concrete, having greater rigidity but lower energy dissipation capability than steel ones, and leading to hysteretic curves with a pinched shape. Steel coupling beams offer several advantages over reinforced concrete (RCC) coupling beams, especially in high-rise buildings and structures subjected to significant lateral loads such as wind or seismic forces. One of the primary benefits is their superior ductility and energy dissipation capacity, which make them highly effective in resisting earthquake-induced stresses. Furthermore, steel beams are less prone to cracking and shrinkage issues, improving long-term durability. Steel coupling beams are preferred in modern design for their superior performance, fast installation, and structural resilience.

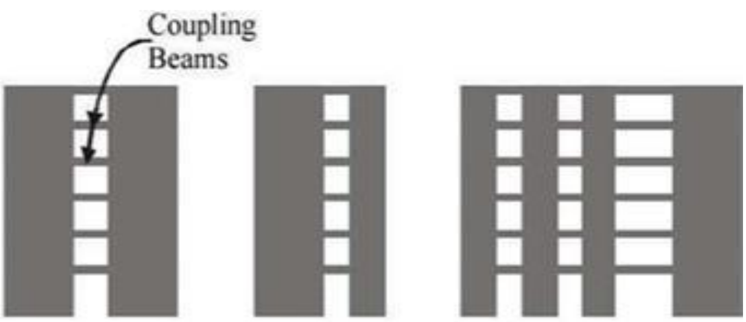

Fig.1 Coupling Beam

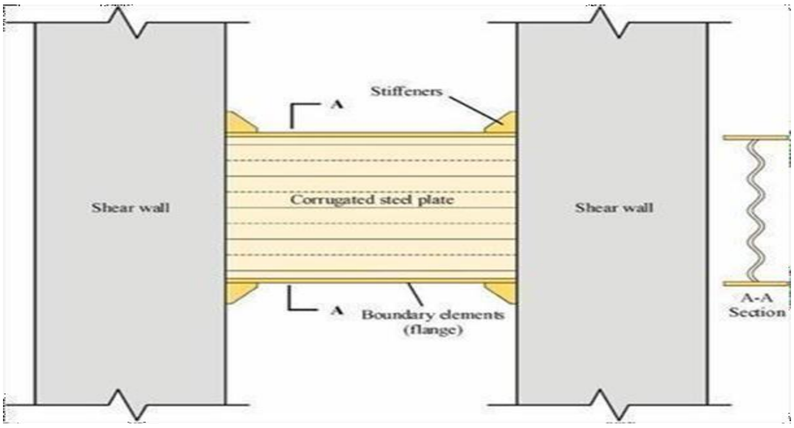

Fig. 2 Compositionof SCPCB

II.THEORETICAL BACKGROUND

Steel coupling beams exhibits good ductility and excellent hysteretic behaviour. Steel coupling beam configurations with stiffeners and Replaceable shear links are designed to concentrate inelastic deformation and damage within the link itself, by protecting the surrounding structural components from significant harm. After seismic events, damaged shear links can be easily removed and replaced without extensive demolition or reconstruction, significantly reducing downtime and repair costs. Hence replaceable links enhance the overall ductility and resilience of the structure under lateral loading.

III. OBJECTIVES

This study focuses on evaluating the Non-linear dynamic analysis of Steel Coupling beam, aiming to enhance the Load carrying capacity, Drift Ratio and Energy dissipation of the structure. A detailed parametric study was also carried out to accesses the influence of various factors on coupling beam.

Coupling beam with Horizontal, Vertical and Combined Stiffeners: The focus was to evaluate the Load carrying capacity and Energy dissipation of the coupling beam with Horizontal stiffeners, Vertical stiffeners, and a combination of both Horizontal and Vertical stiffener, subjected to cyclic loading. Three models of Steel Coupling beams with stiffeners were modelled in order to achieve the intended objectives. Each model is 750mm total span,675mm height and thickness of the steel plate was 5.8mm. Stiffeners of about 80mm width and 10mm thickness were used. Stiffeners are used to prevent early-stage buckling deformations. Stiffeners placed horizontally was intended to provide lateral restraint and to resist shear deformation. Stiffeners placed vertically are for improving resistance to vertical deformation and enhancing overall stiffness and the combination was designed to provide a more balanced structural response under loading conditions. The material property provided are Yield strength, Modulus of Elasticity and Poisson's ratio. The component was modelled in the ZX plane. Support Condition was one end fixed and other end Ux=0, ROTx=0, ROTy=0, ROTz=0. Load was provided in the form of displacement- controlled method. The loading protocols refers to 'Cyclic Tests for Qualification of Buckling- Restrained Braces' of 'Seismic Provisions for Structural Steel Buildings' America (AISC341-10). Standard loading cycles of the first loading protocol is divided into eight levels, corresponding to the drift angle of δ/h being equal to 0.25%, 0.5%, 0.75%, 1.0%, 1.25%, 1.5%, 1.75%, 2.0%. There are two cycles at each loading level. If the specimen does not fail after the standard loading cycles additional loading cycles will be performed, corresponding to the drift angle of δ/h being equal to 2.25%, 2.5%, 2.75%, 3.0%, 3.25%, 3.5%, 3.75%, 4.0%. It is observed that the use of stiffeners in Coupling beam improved the Load carrying capacity and Energy dissipation compared to corrugated coupling beam. The load carrying capacity of Coupling Beam with Horizontal stiffener, at 2% drift ratio is increased by 5.2% and Maximum load carrying capacity is increased of 16.28% and Energy dissipation increased by 8% when compared with Corrugated coupling beam. The load carrying capacity of Coupling Beam with Vertical stiffener at 2% drift ratio is increased by 5.11% and Maximum load carrying capacity is increased by 29.5% and Energy dissipation increased by 14.5% when compared with Corrugated coupling beam. The load carrying capacity of Coupling Beam with a Combination of Horizontal and vertical stiffener, at 2% drift is increased by 12.6% and Maximum load carrying capacity is increased by 40.15% and Energy dissipation increased by 12.8% when compared with Corrugated coupling beam.

Coupling beam with Endplate connection with Shear key: The focus was to evaluate the Load carrying capacity and Energy dissipation of the coupling beam with Endplate connection with shear key of varying thickness in shear link subjected to cyclic loading. Five models of Steel Coupling beams with Endplate connection with shear key were modelled in order to achieve the intended objectives. Each model is 750mm total span, 675mm height and with varying thickness of shear link are 8mm,10mm,12mm,15mm and 16mm.Stiffeners of about 80mm width and 10mm thickness were used. Shear keys enhance the structure's stability against horizontal forces by increasing its resistance to sliding. The material property provided are Yield strength, Modulus of Elasticity and Poisson's ratio. The component was modelled in the ZX plane. Support Condition was one end fixed and other end Ux=0, ROTx=0, ROTy=0, ROTz=0. Load was provided in the form of displacement- controlled method. The loading protocols refers to 'Cyclic Tests for Qualification of Buckling- Restrained Braces' of 'Seismic Provisions for Structural Steel Buildings' America (AISC341-10). Standard loading cycles of the first loading protocol is divided into eight levels, corresponding to the drift angle of δ/h being equal to 0.25%, 0.5%, 0.75%, 1.0%, 1.25%, 1.5%, 1.75%, 2.0%. There are two cycles at each loading level. If the specimen does not fail after the standard loading cycles additional loading cycles will be performed, corresponding to the drift angle of δ/h being equal to 2.25%, 2.5%, 2.75%, 3.0%, 3.25%, 3.5%, 3.75%, 4.0%. It is observed that the use of Endplate connection with shear key in Coupling beam improved the Load carrying capacity and Energy dissipation compared to corrugated coupling beam. The load carrying capacity of 15mmthickness shear link, at 2% drift ratio is increased by 27% and Maximum load carrying capacity is increased of 44.4% and Energy dissipation increased by 51.58% when compared with Corrugated coupling beam. The results clearly indicate that the 15mm thickness shear link configuration shows enhanced performance.

Coupling beam with Splice plate connection: The focus was to evaluate the Load carrying capacity and Energy dissipation of the coupling beam with Splice connection of varying thickness in shear link subjected to cyclic loading. Three models of Steel Coupling beams with Splice plate connection were modelled in order to achieve the intended objectives. Each model is 750mm total span, 675mm height and with varying thickness of shear link are 8mm,10mm and 12mm. Stiffeners of about 80mm width and 10mm thickness were used. The flange splices were designed to resist all the moment at the centerline of the splice. The web splices were designed to resist all the shear force acting at the centerline of the splice. The material property provided are Yield strength, Modulus of Elasticity and Poisson's ratio. The component was modelled in the ZX plane. Support Condition was one end fixed and other end Ux=0, ROTx=0, ROTy=0, ROTz=0. Load was provided in the form of displacement- controlled method. The loading protocols refers to 'Cyclic Tests for Qualification of Buckling- Restrained Braces' of 'Seismic Provisions for Structural Steel Buildings' America (AISC341-10). Standard loading cycles of the first loading protocol is divided into eight levels, corresponding to the drift angle of δ/h being equal to 0.25%, 0.5%, 0.75%, 1.0%, 1.25%, 1.5%, 1.75%, 2.0%. There are two cycles at each loading level. If the specimen does not fail after the standard loading cycles additional loading cycles will be performed, corresponding to the drift angle of δ/h being equal to 2.25%, 2.5%, 2.75%, 3.0%, 3.25%, 3.5%, 3.75%, 4.0%. It is observed that the use of Splice plate connection in Coupling beam improved the Load carrying capacity and Energy dissipation compared to corrugated coupling beam. The load carrying capacity of 10mm thickness shear link, at 2% drift ratio is increased by 10.56% and Maximum load carrying capacity is increased of 25.9% and Energy dissipation increased by 16.38% when compared with Corrugated coupling beam. The results clearly indicate that the 10mm thickness shear link configuration shows enhanced performance.

Coupling beam with Bolted Web Connection: The focus was to evaluate the Load carrying capacity and Energy dissipation of the coupling beam with Bolted web connection of varying thickness in shear link subjected to cyclic loading. Three models of Steel Coupling beams with Bolted web connection were modelled in order to achieve the intended objectives. Each model is 750mm total span,675mm height and with varying thickness of shear link are 8mm,10mm,12mm. Stiffeners of about 80mm width and 10mm thickness were used. The shear link consisted of back- to-back double channel sections, sandwiching the web of the beam segment through an eccentrically loaded bolted connection. The material property provided are Yield strength, Modulus of Elasticity and Poisson's ratio. The component was modelled in the ZX plane. Support Condition was one end fixed and other end Ux=0, ROTx=0, ROTy=0, ROTz=0. Load was provided in the form of displacement- controlled method. The loading protocols refers to 'Cyclic Tests for Qualification of Buckling- Restrained Braces' of 'Seismic Provisions for Structural Steel Buildings' America (AISC341-10). Standard loading cycles of the first loading protocol is divided into eight levels, corresponding to the drift angle of δ/h being equal to 0.25%, 0.5%, 0.75%, 1.0%, 1.25%, 1.5%, 1.75%, 2.0%. There are two cycles at each loading level. If the specimen does not fail after the standard loading cycles additional loading cycles will be performed, corresponding to the drift angle of δ/h being equal to 2.25%, 2.5%, 2.75%, 3.0%, 3.25%, 3.5%, 3.75%, 4.0%. It is observed that the use of Bolted web connection in Coupling beam improved the Load carrying capacity and Energy dissipation compared to corrugated coupling beam. The load carrying capacity of 10mm thickness shear link, at 2% drift ratio is increased by 19.24% and Maximum load carrying capacity is increased of 37.6% and Energy dissipation increased by 43.7% when compared with Corrugated coupling beam. The results clearly indicate that the 10mm thickness shear link configuration shows enhanced performance.

Coupling beam with thin plate on web: The focus was to evaluate the Load carrying capacity and Energy dissipation of the coupling beam with thin plate on web of varying thickness in shear link subjected to cyclic loading. Three models of Steel Coupling beams with thin plate on web were modelled in order to achieve the intended objectives. Each model is 750mmtotal span, 675mm height and with varying thickness of shear link are 8mm,10mm, 12mm.Stiffeners of about 80mm width and 10mm thickness were used. The shear link consisted of back-to- back double channel sections, sandwiching the web of the beam segment. To prevent connection failure due to bolt- hole ovalization of the thin web, the link webs in the connection region were reinforced by 10mm thick plates. The material property provided are Yield strength, Modulus of Elasticity and Poisson's ratio. The component was modelled in the ZX plane. Support Condition was one end fixed and other end Ux=0, ROTx=0, ROTy=0, ROTz=0. Load was provided in the form of displacement- controlled method. The loading protocols refers to 'Cyclic Tests for Qualification of Buckling- Restrained Braces' of 'Seismic Provisions for Structural Steel Buildings' America (AISC341-10). Standard loading cycles of the first loading protocol is divided into eight levels, corresponding to the drift angle of δ/h being equal to 0.25%, 0.5%, 0.75%, 1.0%, 1.25%, 1.5%, 1.75%, 2.0%. There are two cycles at each loading level. If the specimen does not fail after the standard loading cycles additional loading cycles will be performed, corresponding to the drift angle of δ/h being equal to 2.25%, 2.5%, 2.75%, 3.0%, 3.25%, 3.5%, 3.75%, 4.0%. It is observed that the use of Thin plate on web in Coupling beam improved the Load carrying capacity and Energy dissipation compared to corrugated coupling beam. The load carrying capacity of 10mm thickness shear link, at 2% drift ratio is increased by 15.46% and Maximum load carrying capacity is increased of 31.2% and Energy dissipation increased by 37.4% when compared with Corrugated coupling beam. The results clearly indicate that the 10mm thickness shear link configuration shows enhanced performance.

IV.CONCLUSION

The coupling beams can improve the lateral resistance and enhance the structure's integrity and dissipate seismic energy by yielding under a severe earthquake and then reduce its seismic response. The study focuses on Load carrying capacity at 2% Drift ratio and Energy dissipation. Different structures and their parametric studies were carried out to evaluate their effectiveness under lateral cyclic loading conditions. The major findings are as follows:

i. Coupling beams with stiffeners were analyzed, in that Combined stiffener shows an increment of 12.6% in Load carrying capacity at 2% Drift ratio, and Energy dissipation is increased by 12.8% when compared with Corrugated coupling beam.
ii. In Endplate connections with shear keys, 15 mm thick shear link shows an increment of 27% load carrying capacity at 2% drift ratio and Energy dissipation rises by 51.58% compared to Corrugated coupling beam. Obvious damage is observed in the shear link. By increasing thickness to 16 mm, Global buckling in the primary coupling beam is observed.
iii. In case of Splice plate connections,10 mm thick shear link shows 10.59% increase in load carrying capacity at 2% drift ratio and Energy dissipation increased by 16.38% than Corrugated coupling beam. Damage is visibly concentrated in the shear link. By Increasing thickness to 12 mm global buckling of the primary coupling beam occurs.
iv. Shear link with Bolted connections, 10 mm thick shear link shows an increment of 19.3% in load at 2% drift ratio, and Energy dissipation increased by 43.7% than the Corrugated coupling beam. Significant damage is observed in the shear link. By increasing the thickness of shear link to12 mm obvious global buckling was observed in the primary coupling beam.
v. Shear link with Thin plated Connection on web, 10 mm thick shear link shows 15.46% increase in load carrying capacity at 2% drift ratio, and Energy dissipation by 38.7% compared to the Corrugated coupling beam. Significant damage is observed in the shear link. By increasing thickness to 12 mm, resulted in buckling of the primary coupling beam.

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