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# Cyclic and Buckling Analysis of Concrete Filled Steel Pipe Piers with Composite Connection.

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## ABSTRACT

Composite steel-concrete connections are used to protect critical welded interface areas between steel pipe piles and cap beam bridge piers, and can increase the shear capacity of a steel bridge, improving its performance. In this paper, a numerical study using the finite element method was conducted to evaluate the seismic performance of concrete-filled pipe piers with composite steel-concrete connections designed to protect against local buckling phenomena. It was found that the use of composite connections minimized local failure of the steel components by providing confinement through concrete action. Strengthening the connection by filling the hollow pipe pile with concrete helped avoid local buckling and increased the shear force capacity. Buckling and cyclic analysis showed that concrete-filled pipe piers with composite connections reduced buckling while avoiding unfavorable failure modes. Overall, the use of concrete-filled pipe piers with steel-concrete composite connections can improve the performance of bridges, especially in earthquake-prone areas, contributing to ongoing efforts to strengthen bridge infrastructure

**Keywords -** Buckling analysis, Concrete filled pipe pile, Cyclic analysis, steel bridge, Steel- concrete composite connection, Stud connection.

## 1. INTRODUCTION

In seismic regions, critical infrastructure, including steel bridges, may require repairs and strengthening to ensure they can withstand the effects of earthquakes and prevent life-threatening accidents and costly reconstruction. The connection between the steel pipe pile and cap beam in a moment resisting system is a crucial element in controlling lateral seismic loads in steel bridges. The pipe pile to cap beam connection plays a critical role in transferring the seismic forces between the pile and the superstructure, including the cap beam. It is designed to resist the bending moments, shear forces, and axial loads induced during an earthquake event. By ensuring the robustness and reliability of the pipe pile to cap beam connection in steel bridges, the risk of local or global failure during seismic events can be mitigated, contributing to the overall safety and resilience of critical infrastructure in seismic regions.

Steel-concrete composite connections are commonly used in steel bridges, particularly in the connection between steel pipe piles and cap beams. This type of connection provides several advantages, including increased shear capacity and dissipated energy, which can improve the overall performance of the steel bridge. The steel-concrete composite connection typically involves integrating the steel pile and the cap beam with a concrete interface. This can be achieved through various methods such as welding, bolting, or using connectors like shear studs. The concrete serves to enhance the connection by providing additional stiffness, strength, and ductility to the overall system. One of the key benefits of a composite connection is increased shear capacity. The concrete interface can significantly increase the shear resistance of the connection, allowing it to withstand higher loads and improve the overall structural stability. This is particularly important in areas where the bridge may be subjected to heavy loads or seismic forces. Another advantage is improved energy dissipation. The concrete in the composite connection can absorb and dissipate energy during dynamic loads, such as earthquakes or vehicle impacts. This can help reduce the risk of brittle failure in the steel elements, as the energy is absorbed by the concrete, which is more ductile. Overall, steel-concrete composite connections in steel bridges can enhance the structural performance by increasing shear capacity and improving energy dissipation. These advantages can result in a more resilient and durable bridge system that can better withstand various loads and environmental conditions, contributing to the overall safety and longevity of the bridge.

The finite element method was utilized in a previous study to investigate a steel bridge system with two types of connections: a) composite steel connection, and b) direct weld connection (WC). ANSYS software was used to create finite element models. The effects of the length of the composite region and strength of concrete filler were specifically evaluated in the previous investigations. A comparison between a steel bridge with a direct welded joint and a steel bridge with a composite connection revealed that the composite connection increased both the shear capacity and dissipated energy of the steel bridge.

The local buckling phenomena observed in the tubular column immediately after the composite joint in hollow pipe pile composite connections can be mitigated by using concrete-filled pipes, which provide additional load-bearing capacity and reduce brittleness, preventing structural failure. The concrete-filled pipe pile composite connection effectively addresses local buckling, reduces displacement, and increases shear capacity, improving the performance of the steel bridge and ensuring its structural integrity.

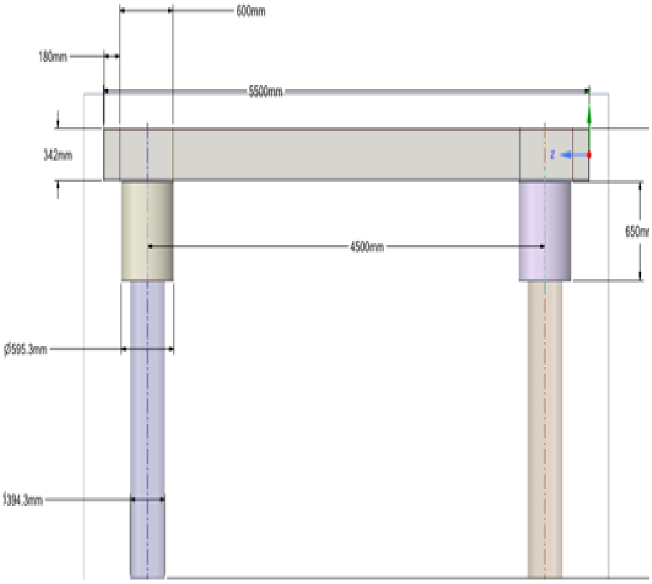


Figure1. geometry of steel-concrete composite connection**.**

## 2. NUMERICAL MODELING OF STEEL-CONCRETE COMPOSITE CONNECTION

The finite element method was employed using ANSYS software to evaluate the steel-concrete composite connection in steel bridge piers. The piers analyzed in this study were comprised of driven hollow circular steel pipe piles and double HP section cap beams, as well as concrete-filled circular steel pipe piles and double HP section cap beams. The span between the pipe piles and the pile height were set at 4.5 m and 2.8 m, respectively. The pipe piles had a radius of 203.5 mm and a thickness of 12.7 mm, with a connector spacing of 130 m between the column and steel cover. M20 grade of concrete was used as the filler material. The analysis investigated the influence of the compressive strength of the concrete filler on the confinement of the steel components and the occurrence of local buckling phenomena

### .2,1 Material properties

The analysis of the steel-concrete composite connection utilizes a combined isotropic-kinematic hardening model to accurately capture the nonlinear behavior of the steel materials. This model accounts for both isotropic and kinematic hardening effects, enabling a realistic representation of the material's response to cyclic loading, plastic deformation, and strain hardening. Furthermore, the stress-strain diagram for the metal materials incorporates the influence of cyclic loading effects, such as material degradation, hysteresis, and strain accumulation.

| | |
|---|---|
| Density | 7.85e-06 kg/mm |
| Young’s modulus | 210000 Mpa |
| Poisson’s ratio | 0.3 |
| Bulk modulus | 1.75e-05 Mpa |
| Shear modulus | 80769 Mpa |
| Compressive ultimate strength | 0 Mpa |
| Compressive yield strength | 317 Mpa |
| Tensile ultimate strength | 428 Mpa |
| Tensile yield strength | 317 Mpa |

Table 1**:** Material properties of Structural steel

In the analysis, the concrete materials are defined using the concrete damage plasticity model, which allows for accurate representation of the nonlinear behavior of concrete under compression and tension. Different compressive strengths of concrete, such as 20 MPa, are considered in the analysis to account for the variations in material properties.. This comprehensive approach ensures that the concrete materials are accurately modeled, taking into account their nonlinear behavior, compressive strengths, and densities, in order to obtain realistic results for the steel-concrete composite connection.

| | |
|---|---|
| Density | 2.3e- 06 kg/mm |
| Young's modulus | 21000Mpa |
| Poisson's ratio | 0.18 |
| Bulk modulus | 10938 Mpa |
| Shear modulus | 8898.3 Mpa |

Table 2: Material properties of Concrete

### 2.2 Boundary conditions and loading parameter

In this study, both the steel and concrete-filled pipe piles are assumed to be pinned at their connections to define the boundary conditions. This type of support allows for rotation but prevents displacement in three directions, providing a realistic representation of the behavior of the piles under cyclic loading. The loads are applied as boundary conditions by imposing cyclic displacements with increasing magnitudes at the end of the cap beam, simulating the cyclic loading pattern that the composite connection may experience in real-world conditions. This allows for the evaluation of the response of the steel-concrete composite connection under cyclic loading, considering the effects of displacement and load magnitude variations.

| Boundary Condition | Location | X | Y | Z | RX | RY | RZ |
|---|---|---|---|---|---|---|---|
| Pin support 1 | Beam bottom(left) | 0 | 0 | 0 | free | 0 | 0 |
| Pin support 2 | Beam bottom(right) | 0 | 0 | 0 | free | 0 | 0 |
| Displacement (Loading) | The right face of the beam | 0 | 0 | Cyclic loading | - | - | - |

Table 3: Boundary condition.

### 2.3 Mesh model

ANSYS meshing capabilities are a valuable tool in reducing the time and effort required to obtain accurate simulation results. Meshing, which involves generating 2D or 3D grids by dividing complex geometries into smaller elements, is an essential step in the finite element analysis process. However, meshing can be time-consuming and challenging, as it requires careful consideration of element types, mesh density, and refinement techniques. These meshes are crucial for ensuring accuracy and convergence in simulations, as they accurately capture the geometry and features of the model being analyzed. Well-defined meshes help in obtaining reliable results and speeding up simulations. In this mesh elemental size is taken as 20mm.

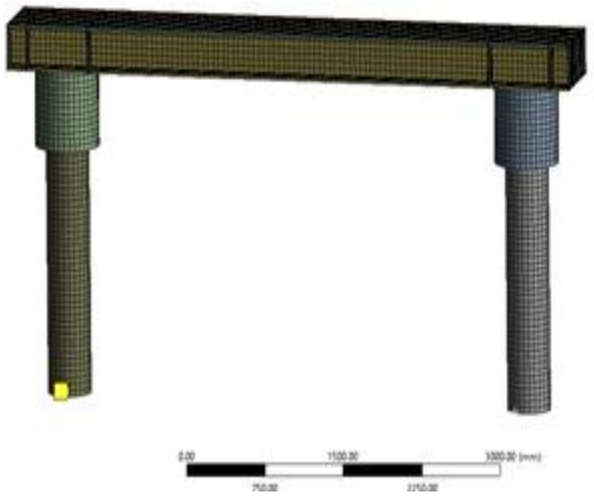


Figure 2: Mesh model of composite connection.

## 3. CYCLIC AND BUCKLIG ANALYSIS

Cyclic and buckling analysis of hollow pipe pile with composite connection and concrete filled pipe pile with composite connection are analyzed. In the cyclic analysis the displacement loading are applied in the Z direction. The displacement load are applied in gradually. Total 35 number of steps and 20 sub step are applied in this model, because the sudden apply of load will cause failure so load will be applied gradually in each step.

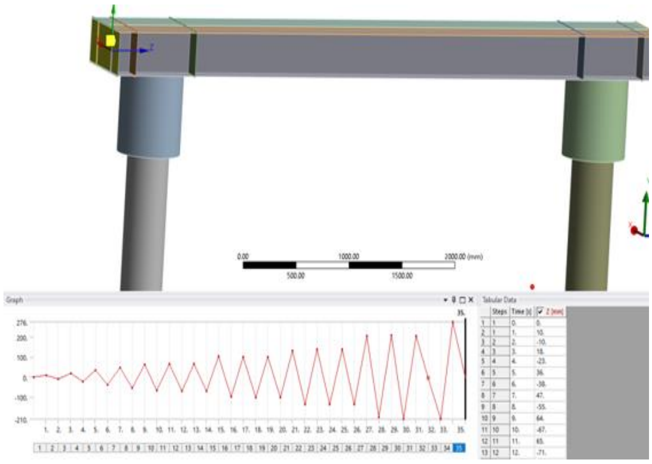
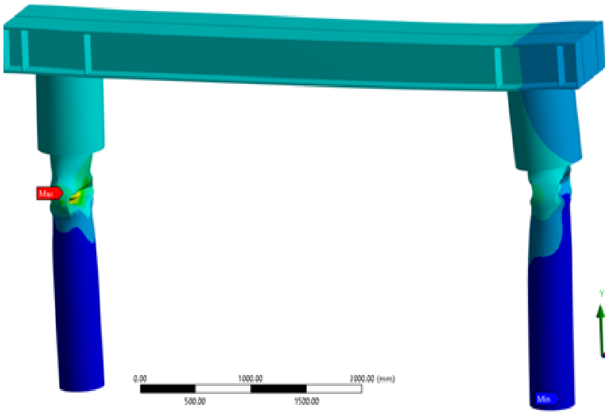


Figure 3: cyclic loading

## 4. NUMERICAL RESULT

### 4.1 Hollow pipe pile with composite connection.

The cyclic and buckling analysis of the hollow pipe pile with composite connection was conducted, and it was observed that buckling within the length of the pile in composite connections does not result in bridge collapse. The figure clearly shows that buckling occurs away from the connection region in the steel bridge with a composite connection between a pipe pile and a cap beam.



.Figure 4: Total deformation of without concrete filling

#### 4.1.1 Hysteresis loop

The force-displacement hysteresis curve shown in the figure depicts the behavior of a steel bridge with a composite connection between a pipe pile and a cap beam under cyclic loading. The curve reveals an initial increase in stiffness during cycles up to 290 mm displacement, followed by a decrease in slope. The maximum force sustained by the steel bridge was recorded as 624 kN. Upon overall analysis of these hysteresis curves, it can be inferred that the utilization of a composite connection has the potential to increase the shear capacity of a steel frame bridge by an average of up to 30%

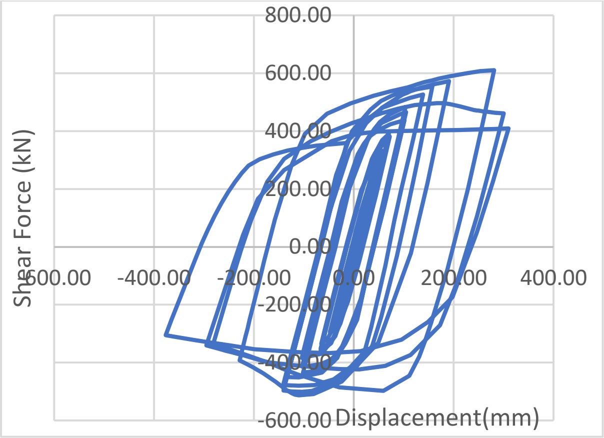


Figure 5: Hysteresis loop without concrete filling

### 4.2 Concrete filled pipe pile with composite connection.

A cyclic and buckling analysis was conducted on a concrete filled pipe pile with a composite connection. In the concrete filled pile has mitigated the local buckling phenomena. In this figure shows that the buckling was disappeared in the pipe pile region, it is clear the concrete filled pipe pile with composite connection will reduces the overall failure.

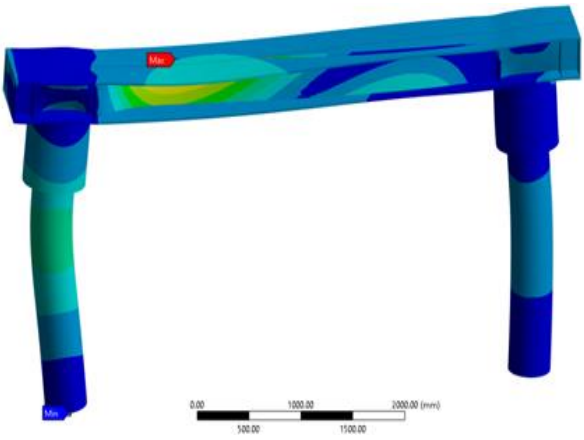


Figure 6: Total deformation of with concrete filling

#### 4.2.1 Hysteresis loop

The figure depicts the force-displacement hysteresis curve for a steel bridge with a composite connection of a concrete-filled pipe pile to a cap beam under cyclic loading. The curve shows increasing stiffness during cycles up to 216mm displacement, followed by a decrease in slope. The maximum force sustained by the steel bridge is 843 kN.

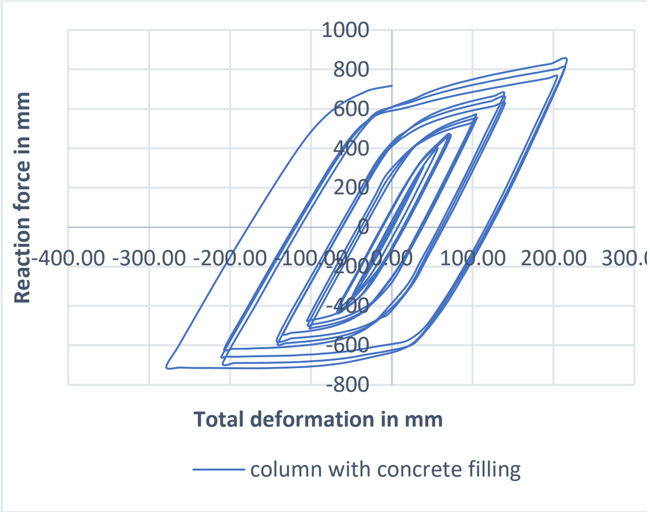


Figure 7: Hysteresis loop with concrete filling

### 4.3 Buckling Comparison

Buckling analysis is conducted on the hollow pipe pile and concrete filled pipe pile. In without concrete filling pile local buckling phenomena is observed away from the composite connection region. In the case of concrete filled pile mitigate the local buckling phenomena

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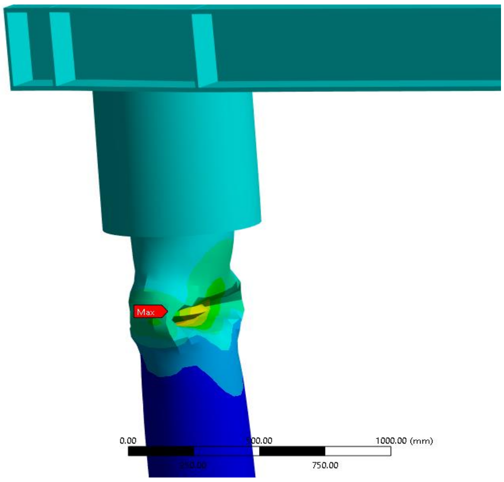

Figure 8: Without concrete filled pipe pile

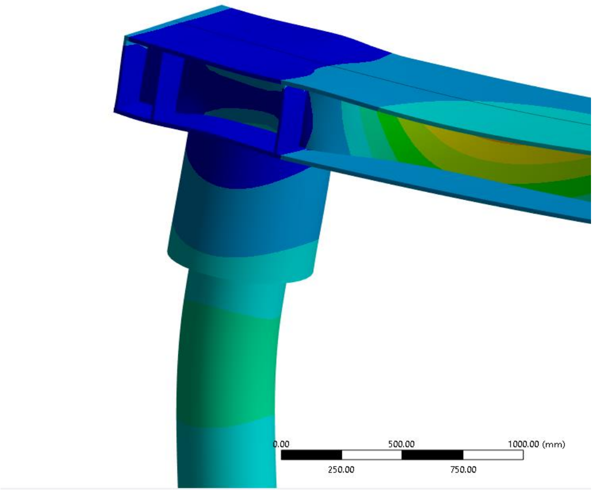

Figure 9: Concrete filled pipe pile

The concrete filled pipe pile has been improved performance of steel bridges, because the displacement in the concrete filled pile has 216 mm it is less than that of without concrete filled pile has 290mm. The shear capacity of steel bridge was increased by the performance of concrete filled pile, because the shear force in concrete filled pile has 843kN it will be grater than that of without concrete filled pile 624 kN.

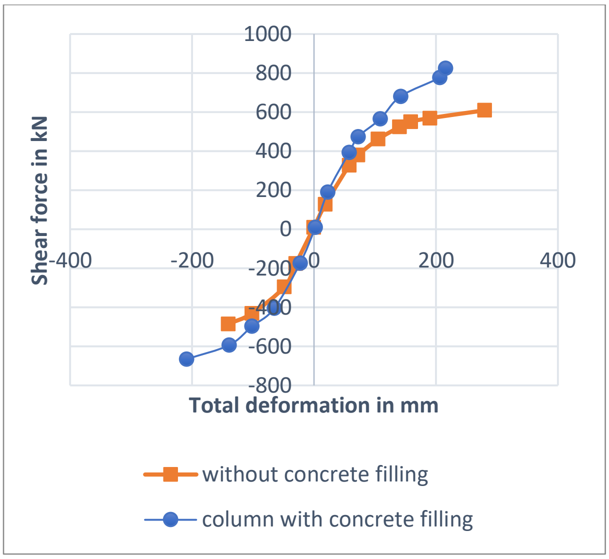

Figure 10: comparison of hysteresis loop

## 5. CONCLUSION

Steel-concrete composite connections are commonly used in steel bridges, particularly in the connection between steel pipe piles and cap beams. This type of connection provides several advantages, including increased shear capacity and dissipated energy, which can improve the overall performance of the steel bridge. Overall, steel-concrete composite connections in steel bridges can enhance the structural performance by increasing shear capacity and improving energy dissipation. These advantages can result in a more resilient and durable bridge system that can better withstand various loads and environmental conditions, contributing to the overall safety and longevity of the bridge. Overall analysis of these hysteresis curves suggests that the utilization of a composite connection could potentially increase the shear capacity of a steel frame bridge by an average of up to 30%.

The findings of the study indicate that there are significant differences in buckling behavior between hollow pipe piles and concrete-filled pipe piles with steel-concrete composite connections. In the case of the hollow pile with a composite connection, buckling tends to occur in the tubular pile column away from the composite connection region. However, in the concrete-filled pile, local buckling phenomena are mitigated. Furthermore, the shear force capacity of concrete-filled piles is observed to be significantly improved compared to hollow pipe piles, with an improvement of 35.09%. This indicates that concrete-filled piles have a higher shear capacity, suggesting that they can withstand higher shear forces compared to hollow pipe piles.

The study's findings suggest that concrete-filled piles with steel-concrete composite connections have several advantages over hollow pipe piles in terms of buckling behavior and shear capacity. Concrete-filled piles are shown to exhibit better performance in mitigating buckling, which refers to the tendency of a structural element to buckle or deform under compressive loads, and improving shear capacity, which refers to the ability of a structural element to resist shearing forces. These advantages can be beneficial in structural design and construction, especially in scenarios where resistance to buckling and shear forces is crucial, such as in deep foundation systems for tall buildings, bridges, and other critical structures. The use of concrete-filled piles with steel-concrete composite connections can potentially lead to more efficient and safer structural designs.

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