Seismic Performance of Exposed Column Base Plates (Phase I)

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Abstract:

Earthquake damage and previous experiments have shown how vulnerable exposed column base plates are to earthquake-induced failures. Following pervious design methodologies, several column base connections did not perform adequately (Hajjar 1). The damage imposed on the base connections consisted of anchor rod elongation (see Figure 2), early anchor rod failure, shear key failure (see Figure 1), concrete crushing (see Figure 1), brittle base plate fracture and separation of nut and base plate (see Figure 3) (Hajjar 1-2). These facts were further enhanced by investigators after the 1994 North Ridge earthquake where several of these connections suffered the damages mentioned earlier (Northridge Reconnaissance Team 1996). However, despite these problems experimental research remains vague in the interactions of all these components especially in the load transfer mechanism from component interaction with the base plate. This was proved by (Hitaka et al., 2003) who showed that many failures were due to moments created by earthquake excitations were transferred by the base plate not prepared to dissipate this energy, thus showing gaps in the understanding of exposed column base plates.

Figure 1 (Anchor Rod Failure and Concrete Crushing)

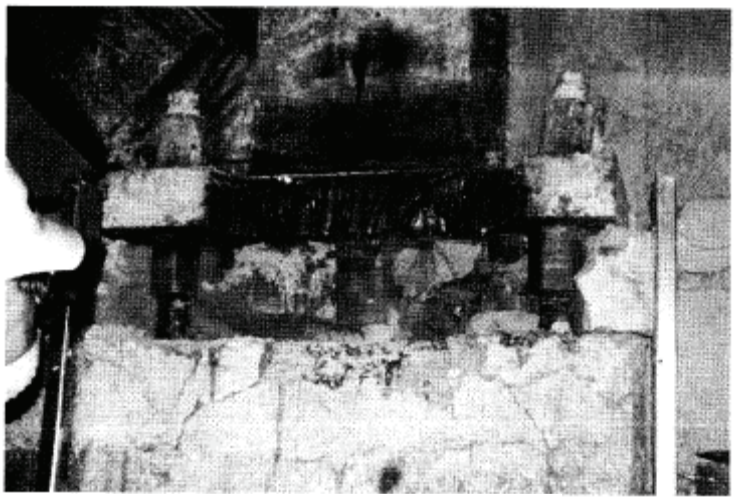
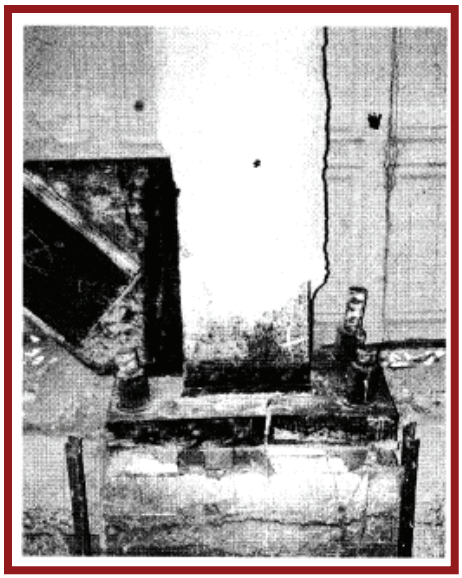


Figure # 1

Figure 2 (left, Anchor Rod Elongation), Figure 3 (right, base plate fracture and separation of nut and base plate), Photos Courtesy of Northridge Reconnaissance Team 1996



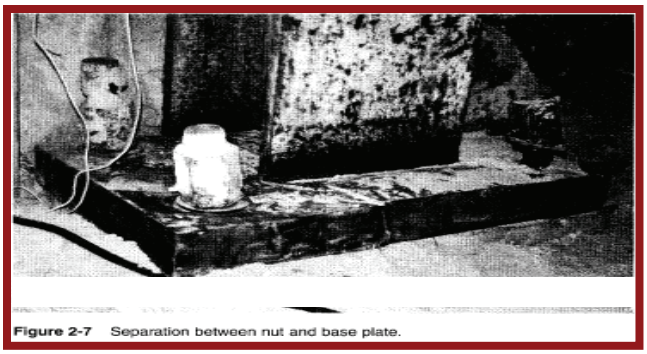


Figure 2-7 Separation between nut and base plate.

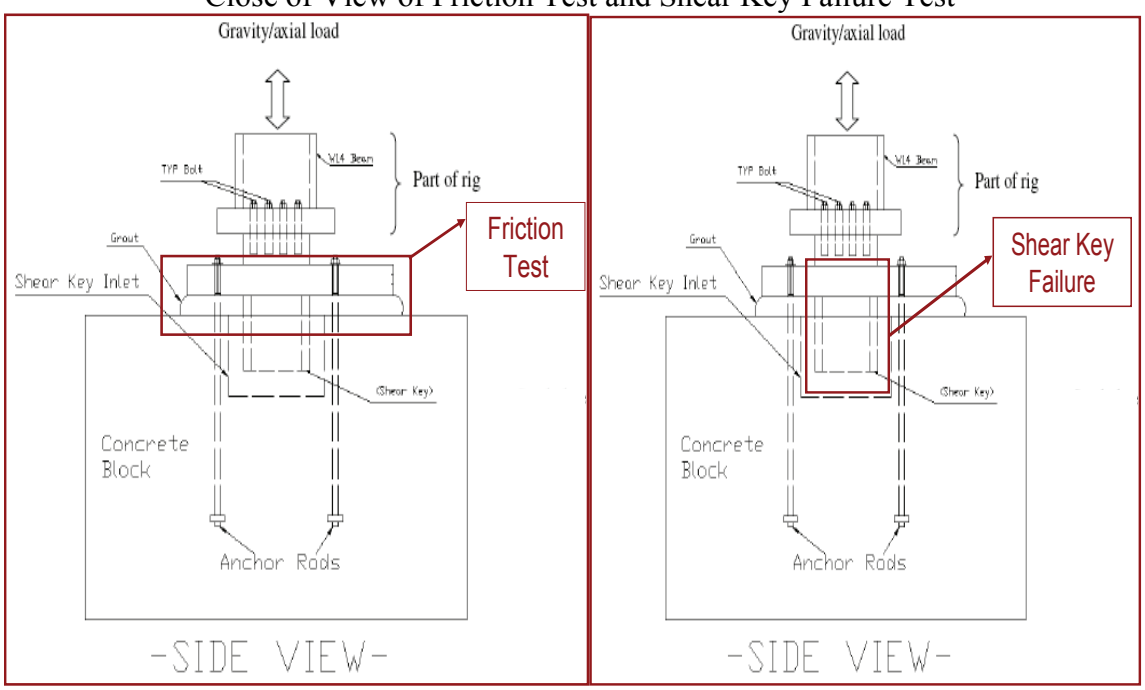
The overall objective of the research will be to develop a better understanding of the behavior of column base plates under the combined actions of shear, flexure, axial load, with the ultimate goal to develop and derive more consistent design methodologies and more ductile column base connections details.

My role in the project as an REU student is to help with the implementation of the test set-up and instrumentation and to analyze and interpret data from the experiments.

Objectives:

Research being conducted on the exposed column base plates will ultimately lead to a better understanding of the behavior of the base plates due to the actions of shear, flexure, and axial load. To reach these objectives the research can be further broken down into three focus areas. Where the first area will deal with characterizing shear transfer mechanism which will emphasize on an improved understanding of the shear transfer mechanisms in column base plate details, including friction and direct bearing against embedded elements (shear key) (see Figure 4). The second area will be directed towards developing an improved understanding of flexure limit states, hierarchies of failure modes and guidelines to design various components to achieve desired behavior. And the last are will be in examining the design and behavior of base plates in braced frames, with an emphasis on the transfer of axial brace force through the base plate details. Once all these three areas are addressed, mechanics-based models and parametric equations will be developed for definition of cyclic hysteresis models that will represent the response of column base connections in nonlinear structural simulations.

Figure 4:
Close of View of Friction Test and Shear Key Failure Test



As mentioned afore, one of the goals of the experimental testing is to develop an improved quantitative understanding of flexure limit states specifically hierarchies of failure. Exposed Column Base Plates usually encompass four major types of failures (Hajjar 5-13).

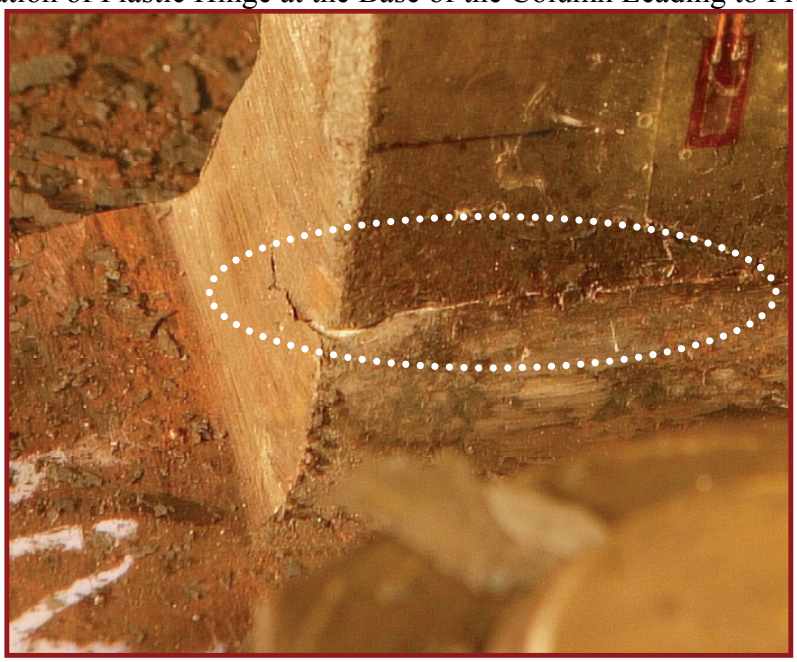
1) Anchor Rods Yielding/Fracture
2) Concrete Failure
3) Plastic Hinge Formation in Column and

4) "Pull-Out" of shear key/lug

Since the entire study is focused on base plate interactions the ideal model for this is a strong column/weak connection. This type of set-up is characterized by inelastic deformation of one or more components of the column base assemblage, as well as the potential brittle failures that are more likely to occur, such as concrete crushing or anchor rod fractures (Hajjar 12-13). With the formation of two or more yield lines, the connection in general shows significant ductility, a higher reduction of the initial stiffness, and a marked drop in the post peak behavior. Some of the characteristics that this type of column base connection may exhibit are low strength and initial stiffness, pinched hysteresis loops, but a good amount of energy dissipation (Hajjar 13). With the increase of the thickness, the strength of the connection is augmented and the ductility reduced.

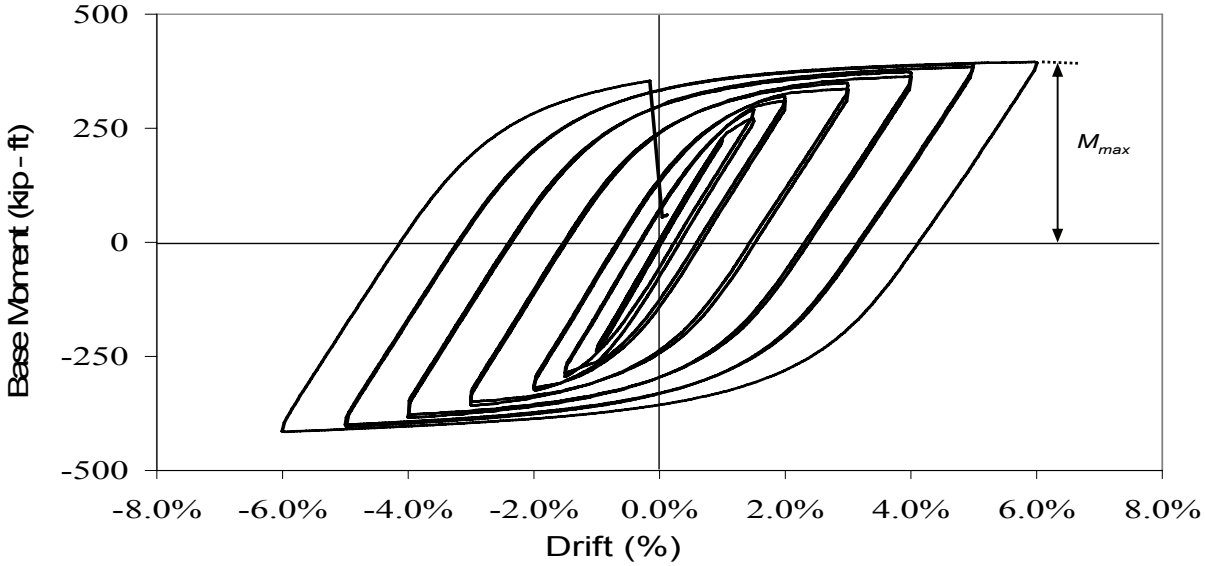
In addition, there can also be a failure when a plastic hinge forms in the column. This usually happens in a weak column/strong connection (NEES Ultra Low Cycle Fatigue Phase II) and are characterized by the formation of a plastic hinge at the base of the steel column (see Figure 5). When this occurs, all other elements in the connection remain basically elastic or may sometimes express incipient yielding. The main characteristics that were observed are the columns high ductility with stable hysteresis loops (see Figure 6) with an increase of the strength of the connection. (Myers 2007).

Figure 5:
Formation of Plastic Hinge at the Base of the Column Leading to Fracture



From the knowledge gained from the previous work done by the PI's (Large Scale Tests and Micromechanics Base Models to Characterize Ultra Low Cycle Fatigue in Welded in Structural Details) where a weak column/strong connection was evaluated. From this data, models can be calibrated and finite element modeling can be used to predict of the entire behavior of the connection. Once this is accomplished then the stress and strain histories at any node within the model can be monitored. (Myers 2007)

Figure 6:
Stable Hysteresis Loops for NEES Ultra Low Cycle Fatigue Phase II

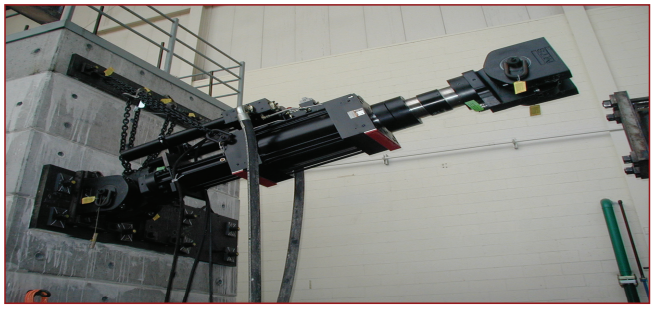


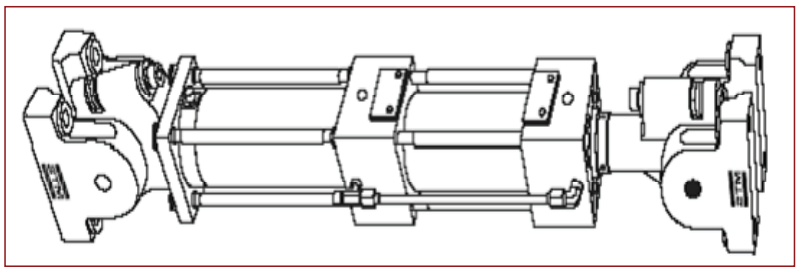
Testing:

The experimental testing phase of this project will be performed at the NEES@Berkeley site located at the Richmond Field Station (Figure 7). The unique opportunity provided by the Berkeley site it's it ability to reconfigure its reaction walls which allow for flexible test set-ups, and actuators that can accomplish both static and dynamic loading which allows for very versatile loading protocols (see Figure 8).

Figure 7:
Richmond Field Station

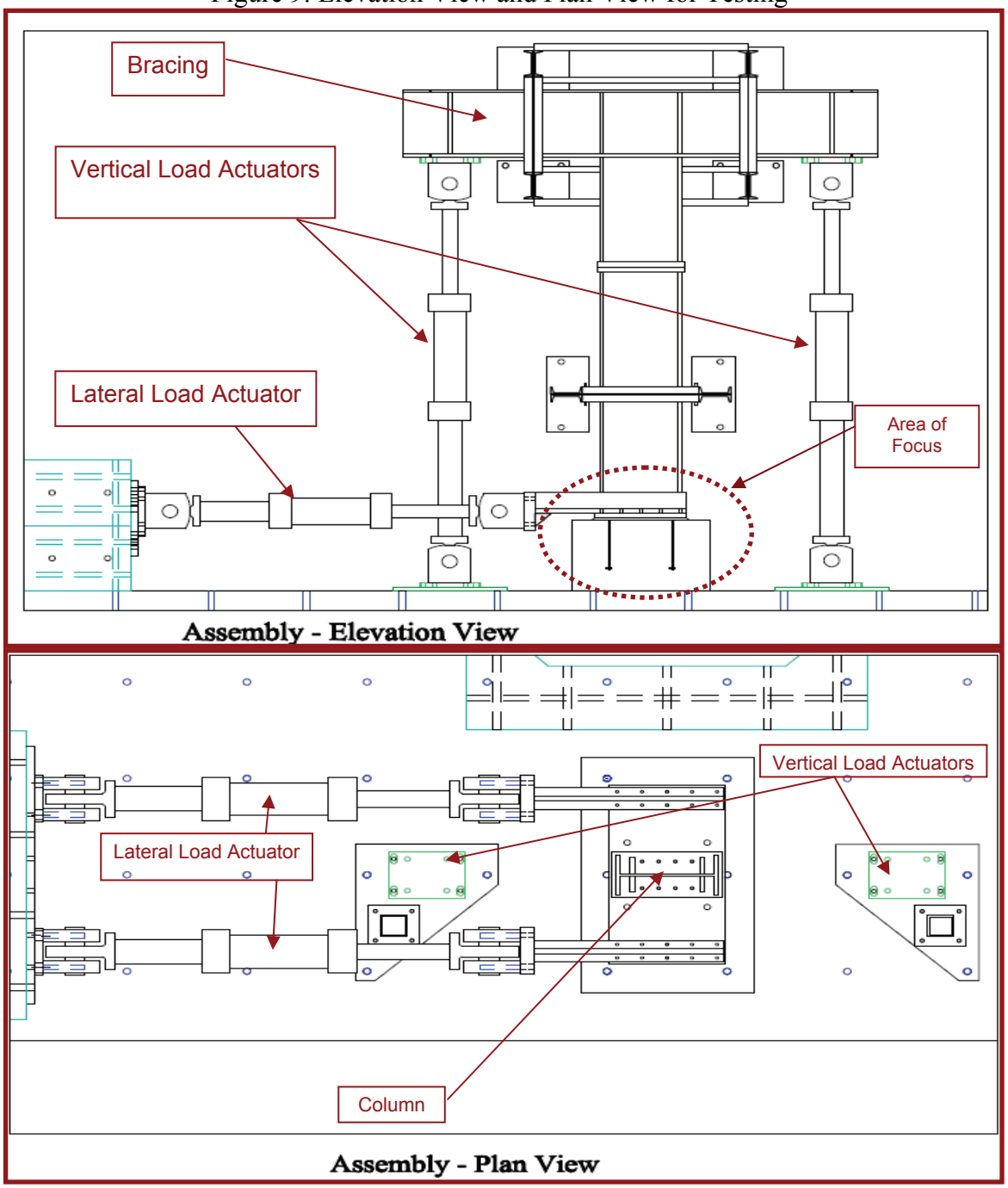
Figure 8: Reconfigurable Reaction Wall (left), Actuators Dynamic and Static (Top and Bottom Right)





The test setup will be elaborate to simultaneously apply both axial as well as lateral loading (Figure 9). The two vertical actuators will be able to provide a 40 inch stroke and provide a maximum force of 150 kips with the two lateral actuators will be able to provide a 20 inch stroke and provide a maximum force of 220 kips.

Figure 9: Elevation View and Plan View for Testing



There will be six test specimens. The test matrix will analyze important section of the exposed column base plate. The first four test will focus will be focused on low or medium shear force demands lower rise structures or non-seismic. The main component that will be investigated is friction type failure and bearing type failure in the anchor rods, including the combined effects of tension, shear and bending in the anchor rods.

The last two test will focus on high-shear applications common to high seismic regions, and will investigate the response of a shear key. All tests will be conducted such that there is minimal eccentricity between the actuator and base plate, to provide a high shear-moment ratio, ensuring a shear type failure that is more likely in base plates in braced frames. Flexure type failure will be investigated in a separate (future) phase of testing.

Test Matrix

Test#	Issue	Concrete Block	Steel Plate	Loads
1	Friction	C1	S1	50 kips (or low) compressive gravity + Pure Shear
2	Friction	C1	S1	250 kips (or high) compressive gravity + Pure Shear
3	Anchor Rods	C1	S1	High uplift/tension + Pure Shear
4	Anchor Rods	C2	S1	High uplift/tension + Pure Shear
5	Shear Lug	C3	S2	No axial load, Pure Shear
6	Shear Lug	C4	S3	No axial load, Pure Shear

All six specimens testing will be conducted such that there is minimal contact between the actuator and base plate. This is done in order to provide a high shear-moment ratio in the specimen thus ensuring a shear type failure that is likely in base plates in braced frames. Flexure type failure will be investigated in a separate (future) phase of testing.

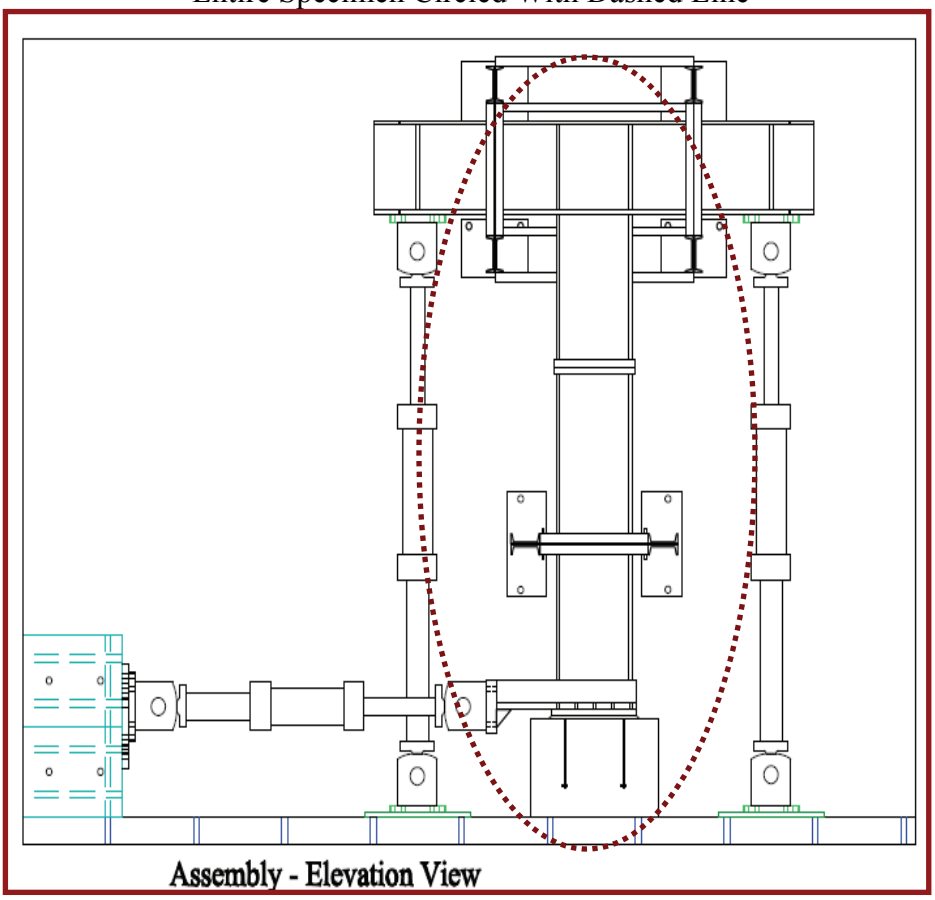
The complexity of the testing and testing rig will be elaborate. The materials used and that will be damaged will be minimal. The tests are designed such that only 3 steel plates and 4 concrete blocks will be damaged during testing. The replaceable components are required to achieve the different conditions of failure. The test rig (beam and column), will permanent and will not be replaced.

Due to scheduling conflicts and material setbacks, testing has been pushed back to the end of September 07, extending into the fall and possibly into the winter.

Future Work:

The hope is now that we have a greater understanding of the behavior of a column under seismic load (Myers 2007) and with the knowledge obtained from the base-plates the ultimate goal is to derive and obtain a micro-mechanical physics based model to predict the behavior of the entire specimen (base plate and columns) and validated these models with experimentation (see Figure 10).

Figure 10:
Entire Specimen Circled With Dashed Line



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