

# *Prototype Cyclic Testing of the SidePlate™ Moment Connection System*

*Northridge Earthquake Research Conference*

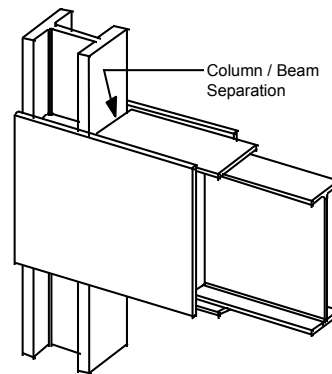
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**SidePlate™ Connection**

## SUMMARY

The *SidePlate™* moment connection system, developed by MNH-SMRF Systems, Inc., looks different because it *is* different. *SidePlate™*'s unique trademark geometry provides *physical separation* between the face of column and end of beam by means of parallel *full-depth side plates*. This innovative feature ensures the *elimination* of *all* brittle behavioral uncertainties responsible for the unprecedented financial losses that resulted from unexpected widespread premature fracture of moment connection welds and base metal discovered after the Northridge earthquake. These well documented uncertainties include 1) *through-thickness* loading of the column flange/heat affected zone, 2) *triaxial/peaked stress concentrations* at the welded beam-to-column juncture, and 3) the reality of construction/U.T. inspection shortcomings, which collectively are intrinsic to *all* other post-Northridge moment connections that employ the use of a T-joint complete-penetration groove weld to connect beam flange directly to column flange. The use of *SidePlate™*'s full-depth side plates also ensures that rotational performance completely avoids dependence on column web *weak panel zone* participation, thus escaping vulnerability to *k-line fracture* syndrome which all other moment connections are subject to.

*SidePlate™*'s robust ductile performance is repeatable and predictable, as demonstrated by its prototype cyclic test performance. The *SidePlate™* moment connection is specifically configured to ensure that all significant energy dissipation/connection deformation occurs *ductilely* outside the column, connection welds and plates. It uses *all shop fillet-welded construction*, inherently ductile weld configurations, and the *column tree/link beam* erection sequence to achieve better quality control and cost efficiencies. Fillet welds are loaded longitudinally in shear which is inherently very *ductile*; eliminating vulnerability to brittle fracture or "unzipping". This is clearly demonstrated in *SidePlate™*'s prototype performance. Test specimens were fabricated using E70T-7 electrodes without regard to notch-toughness. In *all* specimens, connection welds, plates and column remained undamaged while permitting the

beam to develop its full strain-hardened plastic flexural strength, easily satisfying FEMA 267 *Acceptance Criteria*.. No other welded moment connection can *predictably* pass this test.

Cyclic testing of *SidePlate*<sup>TM</sup> includes 1) three *uniaxial* test specimens completed on January 10, 1995 and 2) the first-ever *dual strong-axis* test specimen completed on May 3, 1996. All four test specimens exhibited the predicted *behavior* and *strength* of welds and connecting plates, demonstrating the robustness and dependability of the *SidePlate*<sup>TM</sup> moment connection system to sustain multiple inelastic cyclic rotations with *no* reduction in strength in any of the connection welds, plates, or column, while 1) achieving an average plastic rotation of 0.036 radians for at least one complete cycle, and 2) maintaining a healthy minimum of 83% of the nominal strength of the beam.

The design controls and methodology are supported by a comprehensive connection system qualification, consisting of 1) exhaustive independent scrutiny, 2) heavily instrumented prototype cyclic testing, 3) independent corroborative non-linear analysis, and 4) detailed parametric finite element analyses to justify extrapolation to other member sizes. *SidePlate*<sup>TM</sup> is the first and only moment connection system to date to have been accepted by the *Los Angeles County Technical Advisory Panel* (LACO-TAP) on SMRF over a rigorous 14-month review period (LACO-TAP SMRF Bulletin No. 3 - 97/03). No other moment connection system has undergone this level of technical scrutiny. LACO-TAP is composed of industry-recognized structural engineers and world-renowned researchers.

*SidePlate*<sup>TM</sup> is specified in the design of over 5 million sq.ft. of buildings. It is developed for both new and retrofit construction. Design environments include earthquake, extreme wind, explosive threat, and prevention of progressive collapse. Versatile framing options include uniaxial and dual strong axis applications. *SidePlate*<sup>TM</sup>'s responsive and extensive proprietary research and advanced design development provide engineers with a complete and reliable set of automated design aids, including state-of-the-practice connection design software, *never before available*.

Even more surprising is the low cost of *SidePlate*<sup>TM</sup>. *SidePlate*<sup>TM</sup>'s inherent *increased stiffness* on global frame performance reduces steel tonnage and/or number of moment connections by replacing beam stiffness with connection stiffness to satisfy drift requirements. Nothing as dependable costs less, as demonstrated by a 5-story courthouse in California. Costs were lowered to only \$1450 per ton for fabrication/erection of structural steel. Comparable buildings using other post-Northridge connections have cost \$1750-\$1900 per ton, clearly demonstrating *SidePlate*<sup>TM</sup>'s ability to combine impressive cost efficiency with unprecedented reliability.

The *SidePlate*<sup>TM</sup> moment connection technology is considered by many to be the most important breakthrough in steel moment-resisting frame (SMRF) design and construction in 30 years, as reflected in an official statement by the Los Angeles County Board of Supervisors in April, 1995 that reads: "...*The MNH-SMRF...technology provides the first and only answer to-date to the SMRF connection issue, and will enable the timely completion of Health Facilities Replacement and Improvement Program projects that utilize SMRF systems...saving the County tens of millions of dollars in redesign and critical schedule delay costs.*"

## INTRODUCTION

The geometry, design configuration, and construction methods that characterize the *SidePlate*<sup>™</sup> moment connection technology are clearly and intentionally a *total departure* from the pre-Northridge SMRF connection *norm*. This breakthrough in connection technology eliminates the recognized vulnerabilities inherent with the more “*traditional*” configuration and load paths of other welded steel moment-resisting frame (SMRF) connections through the uniqueness of its trademark geometry and design. These vulnerabilities were identified by researchers over a quarter of a century ago, and were ironically responsible for the abandonment of the Pre-Northridge moment connection following the Northridge earthquake. The type of failure that manifests itself in each of these recognized uncertainties and construction shortcomings is characterized by ATC-24 (1992), *Guidelines for Cyclic Seismic Testing of Components of Steel Structures*, as “rapid deterioration” (refer to Krawinkler et al., -83), or as commonly referred to by researchers, the “*Big Bang!*”

In the wake of unprecedented financial losses following the Northridge earthquake, as well as the potential threat to life safety, *SidePlate*<sup>™</sup> affirmatively responds to both the call for reliable post-Northridge *innovation* that truly eliminates rather than mitigates these recognized vulnerabilities, and the professional obligation of structural engineers to provide building owners with a reliable and predictable SMRF connection system that measures up to the *standard of care* commensurate with the demands of the third millennium.

#### ATTRIBUTES OF THE CONNECTION SYSTEM

**COLUMN/BEAM SEPARATION:** The *SidePlate*<sup>™</sup> solution specifically precludes *brittle* fracture of *any* element within the connection system (including column, plates, welds, and beam) by eliminating, altogether, reliance on the vulnerability of inherently uncertain material properties, unresolved design parameters, and/or the reality of certain construction/U.T. inspection shortcomings. Both *through-thickness* loading of the column flange and *triaxial stress concentrations* at the welded juncture of beam flange to column flange are eliminated by connecting a SMRF beam to a SMRF column by means of parallel full-depth side plates, leaving a physical *separation* or gap between the face of column and end of beam.

It is important to note that random brittle *through-thickness* fractures in column flanges, in the form of a divot pull-out, continue to be observed in test specimens of derivatives of the Pre-Northridge connection. Cautionary *Commentary* in Section 7.5.1, *Material Strength Properties*, of the SAC Interim Guidelines (FEMA 267 -95/08) concerning the uncertainty of column flange through-thickness properties, states “*The causes for through-thickness failures of column flanges..., observed both in buildings damaged by the Northridge Earthquake and in some test specimens, are not well understood.*”, and conclude by saying “*Given the many complex factors which can affect the through-thickness strength of the column flange, determination of a reliable basis upon which to set permissible design stresses will require significant research.*” To date, the author is unaware of any “significant research” that has been done or programmed with adequate funding.

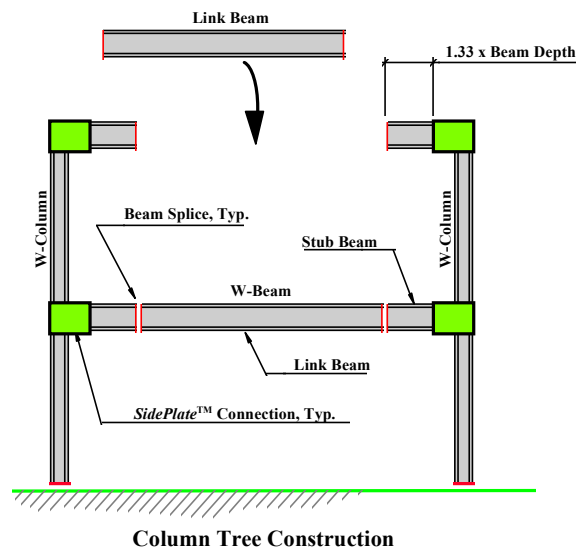
**FULL-DEPTH SIDE PLATES:** The use of full-depth side plates ensures that the rotational performance of the frame completely *avoids* dependence on column web *weak panel zone* participation, thus escaping vulnerability to the *k-line fracture* syndrome identified by the American Institute of Steel Construction (AISC Advisory Statement on Mechanical Properties

Near the Fillet of Wide Flange Shapes and Interim Recommendations - 97/01/10). Rolled shapes from the mill are subject to material variations in the “k” area that include a significant reduction in ductility and fracture resistance ( i.e., Charpy V-notch toughness below 5 ft-lbs at 70° F). It is important to note that weak panel zones have been shown in test specimens of the Pre-Northridge connection and its derivatives to contribute to random brittle fractures in column webs, even with designs that strictly conform to both current panel zone strength and stiffness limitations in the code, as well as the design, fabrication and inspection guidelines contained in the SAC Interim Guidelines. Tests conducted by Yang and Popov (UCB/EERC -95/08) concluded that current code limitations on panel zone strength and stiffness are *inadequate* for connections that rely on panel zone participation to achieve rotational capacity.

Another significant attribute of *SidePlate* is the *increased stiffness* provided by the full-depth side plates on the building frame as a whole. In assessing the cost impact of the connection system, the *global* costs associated with the effect of the connection’s own stiffness on the overall frame geometry and sizing of SMRF members must be considered. The connection configuration stiffens the global frame performance, effectively *reducing* steel frame tonnage and/or number of required moment connections by replacing beam stiffness with connection stiffness to satisfy building drift requirements. In order to capitalize on this attribute, *SidePlate*’s connection stiffness can be simulated by using 100% rigid end offset in the panel zone and by increasing the beam’s moment of inertia,  $I_x$ , to approximately  $4 \cdot I_x$ , for a distance of the depth of the beam,  $d_b$ , beyond the face of column flange. Accordingly, the tonnage of SMRF system steel can be reduced on the average of 18 percent, amounting to a reduction in the total beam/column rolled shape steel tonnage of 7-11%.

**SHOP FILLET-WELDED CONSTRUCTION:**

*SidePlate* uses shop fillet-welded construction to connect SMRF beam to side plates, and side plates to SMRF column, under conditions easier to control than in the field. This results in better quality and economy. Fillet welds are loaded primarily along their length in shear which is inherently very ductile. Fillet welds have historically performed well during earthquakes and require no ultrasonic inspection. The consistent test record of *SidePlate* corroborates this history and demonstrates that fillet welds in an imperfect world (i.e., containing inadvertent flaws and discontinuities), loaded in their ductile direction, can successfully fulfill their function without failure or significant damage. Brittle fracture or “unzipping” is altogether eliminated.



To maximize quality control and cost efficiencies during fabrication, the connection system is configured as shop-fabricated *column tree* assemblies that are then shipped to the job site and splice-connected with link beams to complete the frame system.

In sharp contrast to the *SidePlate* connection system, the T-joint CJP groove-welded juncture of beam flange to column flange is a design characteristic *common* to *all* derivatives of the Pre-Northridge connection. Despite post-Northridge efforts to use high fracture resistant (i.e., high notch-tough) electrodes, remove backing bars, back-gouge, and provide reinforcing fillet welds, coupled with the application of correct UT inspection techniques, random brittle fractures in tested connections continue to be reported. These fractures occur either in the weld metal or in the heat affected zone. Omer W. Blodgett, Sr. Design Consultant with The Lincoln Electric Company, raises the fundamental issue of whether ductility can take place with type of connection, even with a *perfect* weld in this region, due to triaxial stress concentrations at this welded juncture (Reference 5.3e, SAC 95-01 *Advisory No. 3 - 95/02/01*).

The steep bevel of the prepared flange surface and the restricted geometry of interfacing elements (notably at the bottom flange) of the T-joint CJP groove weld restrict visibility and access for both the welder and in-process inspector. This type of groove weld configuration is therefore *inherently troublesome*, especially when coupled with hard-to-control variables associated with field welding. In addition, because of limited access and obstructing elements, ultrasonic testing (UT) is *not* always able to detect defects, casting further doubt on the reliability of this type of welded joint. This fact has been acknowledged by researchers after examining the fractured surfaces of weld cracks following testing, and discovering significant weld flaws and discontinuities that had been undetected before testing, despite the use of standard UT inspection procedures.

Due to the relatively large volume of molten weld metal deposited locally, and the fixed boundary conditions of the SMRF beam spanning between SMRF columns, the finished T-joint CJP groove weld is also *highly-restrained* (pre-loaded) in the column flange through-thickness direction, precisely where the moment *demand* is maximum. The author is again unaware of any post-Northridge test program of a connection that features the T-joint CJP groove-welded beam-to-column juncture that has incorporated this highly-restrained condition into the test setup, despite clear instructions in Section 7.4, *Guidelines for Connection Qualification by Testing*, of the SAC Interim Guidelines which state “*The testing program should replicate as closely as practical the anticipated conditions in the field, including such factors as: ...Induced stresses because of restraint conditions on the welds and connection members*”. Simply stated, the effect of a highly-restrained condition produced by weld shrinkage of T-joint CJP groove welds at each end of a SMRF beam can only be assessed *if* the test specimen is loaded to replicate this imposed constraint.

ELIMINATION vs. MITIGATION: *SidePlate* uniquely combines load-transfer simplicity with proven fabrication practices and tested material properties, including ductile fillet weld configurations. Collectively these attributes exhibit a more-forgiving tolerance for accommodating the less-than-perfect *realities* of today's steel fabrication, erection and inspection practices, including the observed random and inordinate variations in the material properties of rolled shapes observed in steel produced by steel mills throughout the world (Kuwamura, et al., *Journal of Construction Steel Research* 13-89; Huang and Schriber, *NCSEA STRUCTURE - 97/01*).

The connection utilizes simplified load paths that do not rely on mechanisms that are subject to unreliable, brittle, or indeterminate behavior. All *SidePlate* tests consistently show that reliable and repeatable connection performance, including weld metal ductility and robustness, are achieved when due design consideration is given to 1) the *direction* of applied load on a weld,

with or without the use of high notch-tough weld metal, and 2) the *elimination* of reliance on recognized uncertain material properties such as through-thickness. Conversely, a significant and uncomfortable number of tests of *derivatives* of the Pre-Northridge connection still randomly demonstrate the unreliability of "Big Bang" properties, in the form of unexpected brittle fracture of weld metal, column flange kinking and sudden panel zone rupture, and/or column flange divot pullout, despite 1) the *intentional* use of high notch-tough weld metal, and 2) removal of backing bar, backgouging, providing a reinforcing fillet weld, and an *initial healthy pedigree* provided by a negative UT inspection report (i.e., no weld discontinuities or base metal defects detected prior to testing, using accepted ultrasonic testing techniques).

The following documented examples illustrate the marked difference in test specimen performance between *elimination* measures versus *mitigation* measures to address recognized vulnerabilities in SMRF connections. The underlining of certain text has been added for emphasis.

### **Results of Elimination Measures:**

Example No. 1: The inherent ductility of fillet welds is clearly demonstrated in the prototype performance of *SidePlate*. Test specimens were fabricated without regard to notch-toughness requirements using E70T-7 weld metal which is known to exhibit very low fracture resistant (i.e., low notch-tough) properties of approximately 4-5 ft.lb. at 70°F, similar to E70T-4 electrodes. It is important to note that the majority of weld metal deposited in Pre-Northridge SMRF connections was E70T-4 electrode. Connections using this weld metal prematurely failed in brittle fracture during the earthquake at strain levels well below yield strength (i.e., less than 0.5  $F_y$ ). All *SidePlate* prototype test specimens easily satisfied the *Acceptance Criteria* for connection qualification in Section 7.4.2 of the SAC Interim Guidelines.

Despite the *severe curvature* of beam flange local buckling, exhibited to the right, and despite the use of low notch-tough weld metal in all three test specimens, only minor shear rupture developed between the end of longitudinal fillet weld and the edge of beam top flange. This localized deterioration occurred gradually, in a ductile manner, *well after* each tested connection had successfully allowed the beam to deliver a demand equal to the maximum strain-hardened flexural capacity of the beam, i.e., a demand of about 15% in excess of the actual plastic moment,  $M_p$ . The rupture length was confined to a very small region approximately 1 to 1-1/4 in. long at the tail end of a 3/4 in. fillet weld connecting cover plate to beam flange. (Uang, et al., UCSD - 95/03).



It should be noted that although low notch-tough weld electrodes were successfully used in the testing of all *SidePlate* prototype specimens, MNH-SMRF Systems, Inc. considers it prudent to use high notch-tough electrodes in the fabrication of its connection in severe design environments such as earthquake.

**Results of Mitigation Measures: ( Examples 2, 3, 4, 5)**

The aim of developers and researchers of post-Northridge derivatives of the Pre-Northridge moment connection is to push the severe curvature exhibited in *Example 1* as far away as possible from the T-joint CJP groove-welded juncture of beam flange and column flange, in order to mitigate connection vulnerabilities from 1) construction imperfections inherent with this troublesome joint configuration, and 2) through-thickness strains in column flange base metal that are exacerbated by the warping effect of out-of-plane strains at that welded juncture caused by lateral torsional buckling of the restrained beam flange and/or severe curvature of same. Some of these derivatives attempt to do this by *surgically* creating localized reduced cross-sections or slots to modify the geometric stiffness properties of the rolled beam, with and without vertical rib reinforcement plates.

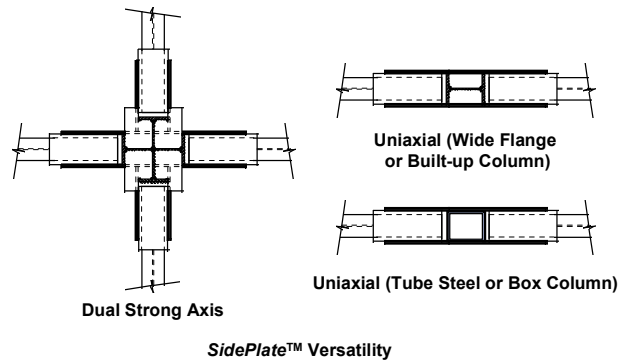
During more recent testing conducted at the University of California, Berkeley, the project engineer reported that "...large shear deformations in the column panel zone...caused severe kinking in the column at the connection. Failure appeared to have started in the web/flange fillet of the column and progressed through flange and into web of the column." (Obeid, SEAONC-96/07).

Example No. 2: The performance report of *cover-plate connection* test specimen 5B, tested at the University of Texas, Austin on July 22, 1994, stated that the specimen "...failed after four inelastic loading cycles. Failure occurred by a sudden and complete fracture at the beam's bottom flange connection. The fracture appeared to be completely within the column flange material, and penetrated relatively deep into the column flange. Portions of the fracture penetrated approximately one inch into the column flange. The fractured surface does not appear to be indicative of lamellar tearing. Failure of the bottom beam flange connection was accompanied by fracture of the fillet welds connecting the shear tab to the column flange, over the full height of the shear tab."(Engelhardt and Sabol, UTA - 94/10/01)

Example No. 4: The *reduced beam section* (RBS or "dogbone") test specimen report in Modern Steel Construction, April 1996, states that, "Test 4 was terminated after the first 4 delta cycle after the top flange connection failed by rupture of a divot from the column flange; rupture initiated in the heat-affected zone and propagated through the parent material in the column." (Iwankiw and Carter, Modern Steel Construction - 96/04)

Conclusion: The author is unaware of any other post-Northridge welded SMRF connection that has achieved the remarkable level of reliability, repeatability, and robust connection integrity of *SidePlate*. Its unique configuration eliminates the recognized vulnerabilities and provides the *performance difference*.

VERSATILITY: *SidePlate* has been developed for both *new* and *retrofit* construction. Ample framing options include both one-sided and two-sided uniaxial connections using rolled or built-up wide flange beams, and columns consisting of either rolled wide flange shapes, tube steel, or built-up box columns. In addition, the system qualification of this connection technology includes two-, three-, or four-sided dual strong axis



connections with cruciform columns, for biaxial applications to resist the orthogonal effects of earthquake forces acting on the same connection. For *general frame* applications in base-isolated buildings, *SidePlate* provides the necessary additional global frame stiffness to permit an *economically viable* combination of a steel SMRF superstructure coupled with a low period (T) foundation system.

#### CONNECTION SYSTEM QUALIFICATION

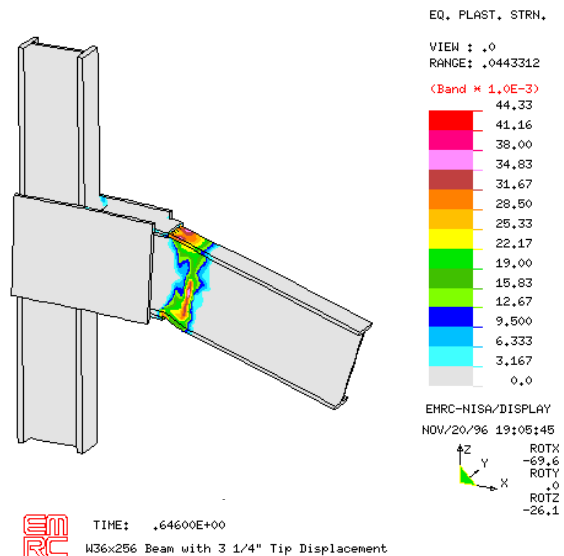
PROTOTYP CYCLIC TESTING: Full-scale cyclic prototype testing of the *SidePlate* connection system was conducted to determine the plastic rotational performance and confirm the strength of connection elements, including welds. Testing of the prototype uniaxial connection was completed on January 10, 1995 at the University of California, San Diego under the direction of Professor Chia-Ming Uang. The three uniaxial test specimens consisted of a W36x150 beam connected with full-depth side plates to a W14x426 column. On May 3, 1996, MNH-SMRF Systems, Inc. successfully tested the *first ever* full scale dual strong axis connection, also under the direction of Dr. Uang. The dual strong axis specimen consisted of W36x170 beams connected with side plates to a built-up cruciform column fabricated with W36x230 sections in each principal direction to form a three-sided SMRF connection. All four test specimens were heavily instrumented to record actual strain histories at critical locations in order to corroborate design controls imposed on key elements.

Dr. Uang reported that “*In all four MNH-SMRF test specimens, the connection plates and welds remained undamaged while permitting the beam to develop its full strain-hardened plastic flexural strength. ...At the plastic hinge location...the connections allowed the beams of all the specimens to strain harden and exceed the actual plastic moment,  $M_p$ , by about 15%. ...The observed performance clearly indicated that, as it was intentionally designed for, the location of the energy dissipation was kept outside of the beam cover and side plates.*” The average actual plastic rotation capacity achieved was 0.036 radians, for at least one complete cycle in accordance with the *Acceptance Criteria* of Section 7.4.2 of the SAC Interim Guidelines/FEMA 267, ranging from 0.030 to 0.039 radians (Uang et al., UCSD - 95/03, 96/05).

All tested MNH-SMRF *SidePlate* connections exhibited the predicted *behavior* and *strength* of welds and connecting plates as determined by finite element analysis, demonstrating the robustness of the connection to sustain multiple inelastic cyclic rotations with *no* reduction in

strength in any of the connection plates, weld elements, or column. The reported rotational performance was achieved while maintaining a healthy minimum of 83% of the nominal strength of the beam. All tests demonstrated ductile behavior of the beam, as evidenced by significant flange and web local buckling, which continued through final rupture of the beam. In all tests, the mode of failure consisted of a crack initiating in the beam flange, that propagated transversely across the flange in a *gradual ductile manner* and eventually fractured the beam. The actual location of the plastic hinge was predictable and consistent at  $d_b/3$  beyond the extent of the side plate. The dual strong axis test demonstrated that the *SidePlate* connection technology can be used for biaxial applications and that orthogonal effects of earthquake forces can be successfully resisted.

NON-LINEAR ANALYSIS: Independent non-linear analysis of the prototype test specimen was performed at the University of Utah, under the direction of Professor Janice J. Trautner. The computer analysis utilized actual material strengths and non-linear properties obtained from prototype coupon tests, and was executed using EMRC NISA II and Display III software. This study demonstrated that *non-linear analytical verification* of the prototype's beam failure mode, location of predicted hinge formation, measured distribution of applied load through critical load transfer mechanisms, and behavior of connection components can be reliably achieved (Trautner, UU-95/09). This conclusion is truly meaningful *only* because the significant contributors to rapid "Big Bang" deterioration have been altogether *eliminated*.



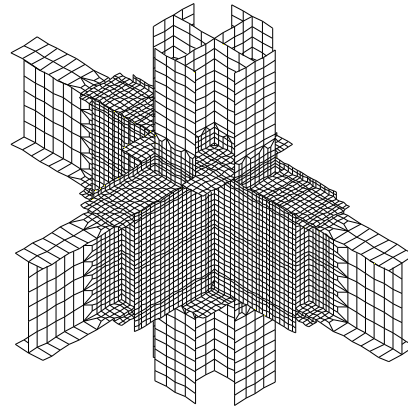
Non-linear analysis of SMRF connection systems that rely on these vulnerabilities, by definition, can not capture the random and brittle behavior of these unreliable properties. Accordingly, non-linear analysis of that type of connection may be deceptive as an analytical tool to rationalize and corroborate the actual tested behavior.

Dr. Trautner concludes "*The non-linear finite-element analysis of the prototype MNH-SMRF moment connection demonstrated the ability of the beam to develop a ductile mode of failure without significant yielding of the connecting elements.*"

FINITE ELEMENT PARAMETRIC ANALYSES: Strain readings measured at key connection locations during both the prototype and dual strong axis tests were consistently either at elastic or controlled plastic levels. These readings are corroborated by the results of the prototype non-linear analysis. This fortuitous fact is *peculiar* to *SidePlate* and provides the technical *basis* for the use of linear-elastic finite-element modeling of the connection as a reliable and convenient analytical tool to simulate the actual behavior and to explore reasonable limits of *extrapolation* to member sizes other than those tested. Accordingly, parametric finite-element linear-elastic analyses were performed to rigorously investigate the behavior of the connection, including the load demand through each critical load transfer mechanism for member sizes other than those tested. Detailed finite-element modeling of side plates was also performed to develop design

controls that ensure *controlled plasticity* is maintained at a predictable and safe level, and that this design-controlled strain level is compatible with actual behavior, as determined by both the prototype cyclic testing and non-linear analysis. This extensive suite of analyses was conducted under the author's direction by Jesse E. Karns, P.E. and Kenneth D. O'Dell, P.E. of Myers, Nelson, Houghton, Inc. - Structural Engineers.

Three-dimensional finite-element CSI SAP90 models were created for both uniaxial and dual strong axis connection configurations. Uniaxial models consisted of the prototype (W36x150 beam and W14x426 column), *upper-bound* (W36x300 beam and W14x500 column) and *lower-bound* (W21x50 beam and W14x90 column) connections. For the prototype member sizes, both single-sided and double-sided connections were modeled. The dual strong axis models (W36x170 beams and W36x230 column sections) consisted of both the three-sided and four-sided connections.



**Finite Element Analysis: *SidePlate*™  
Dual Strong Axis Connection**

Compatible *linkage* between 1) the measured strains and the distribution of applied load through critical transfer mechanisms obtained from the prototype cyclic testing, and 2) the same information analytically computed from the results obtained from both the prototype non-linear and linear elastic analyses was clearly demonstrated. This fact, coupled with detailed parametric analyses addressing relative flange compactness considerations for beams ranging in size from the selected lower-bound beam to the higher-bound beam, qualify the extrapolation of connection implementation to other member sizes within this range *without* the need for additional testing. This is done by interpolating between the prototype size and the upper and lower-bound beam sizes, respectively. These parametric analyses using *SidePlate* include a detailed finite-element study of the effects of beam flange *compactness* on inelastic strains in SMRF beam flanges. Two beams, a W36x150 ( $b_f/2t_f = 6.4$ ) and a W36x256 ( $b_f/2t_f = 3.5$ ) were used in the study. The inelastic flange behavior of the W36x256 showed an almost uniform strain level across the flange width. In contrast, increased localized strain levels, approximately 30% larger than the peak strain observed in the W36x256, were observed on the less compact W36x150. The study concluded that since beam flange strain level is proportional to rate of beam degradation, increased beam flange compactness will actually retard beam inelastic degradation.

#### IMPLEMENTATION

GENERAL: The proprietary *SidePlate* moment connection technology is owned and developed by MNH-SMRF Systems, Inc., with patents pending in both the United States and Japan, as well as other foreign countries. MNH-SMRF Systems, Inc. is a product technical services company dedicated to providing practicing structural engineers of record and their respective building owners with a truly *reliable, versatile, and cost-effective* moment connection system for steel frame buildings. Use of the *SidePlate* connection technology by structural engineers and others, including technology transfer of all research, design development, and design and construction

aids, is authorized and readily available through MNH-SMRF Systems, Inc. by way of license agreement, on a project-by-project basis. *SidePlate* is specified as a *product* on the construction documents by the structural engineer of record. The licensing fee is paid upon issuance of the building permit, as part of the building owner's construction cost. Controlled authorized use of this connection system is done to ensure proper implementation by the engineer of record, as well as proprietary protection of the technology in accordance with United States and Foreign Patent and Intellectual Property Laws.

COST EFFECTIVENESS: In March, 1996, Henningson, Durham & Richardson, Inc. (HDR), a national A/E firm, completed a detailed cost comparison study on a new courthouse building in Southern California. The courthouse is a 5-story, 2013 ton steel frame building. The comparison was made between a pre-Northridge design, and the *SidePlate* and bottom haunch connections featured in the SAC Interim Guidelines. The pre-Northridge design contained mixed lateral load-resisting systems consisting of a SMRF system in the longer building direction and an eccentrically braced frame (EBF) system in the narrow building direction. The EBF was originally selected to control drift. The narrowness of the EBF bay necessitated the use of rock anchors to resist overturning. It is important to note that capitalizing on the increased connection stiffness of *SidePlate* allowed the use of a SMRF system in the narrow direction of the building, while still satisfying drift control. Unit fabrication costs for each connection were provided by Herrick Corporation, including all plate costs. The study included *global* building considerations, including relative steel tonnage for SMRF and EBF (as applicable), number of connections required, and foundation implications for each cited connection system. The results of this study showed that using *SidePlate* reduced the total steel tonnage by 220 tons (representing a 32% reduction in steel tonnage of the SMRF system). This resulted in significant net cost savings, including allowance for licensing fees, when compared to the pre-Northridge and bottom haunch designs.

#### CONCLUSIONS

The *SidePlate* connection system truly *eliminates* rather than mitigates the recognized material vulnerabilities and inherent construction shortcomings of all other welded SMRF connections. This cost effective design breakthrough compels structural engineers to seriously question the *prudence* of proceeding into the third millennium with resigned acceptance of and continued reliance on 25-year old uncertainties inherent in all post-Northridge derivatives of the Pre-Northridge connection. This is especially true in light of the collective enormity of growing technical dilemmas and variations in rolled shape material properties confronting researchers, steel producers, steel fabricators and erectors, and structural engineers who might attempt to resolve these uncertainties.

Because of an unwavering commitment by MNH-SMRF Systems, Inc. to "*zero tolerance*" for continued reliance on "Big Bang" vulnerabilities and inherently difficult-to-control construction shortcomings, the *SidePlate* solution to the steel frame moment connection crisis was conceived, fully developed, and qualified as a truly reliable connection system. The result is a cost-effective robust moment connection system that performs the way structural engineers always intended, i.e., predictable and repeatable ductility, good energy dissipation and balance of capacity, with no significant plastic deformation in the connection's plates and welds, or in the column.

No other SMRF connection *as dependable* as *SidePlate* costs less. No other SMRF connection is as dependable. Its responsive and extensive proprietary research, full-scale cyclic testing, and advanced design development, including unparalleled independent scrutiny, clearly restore the lost confidence in steel frame buildings following the Northridge earthquake, as well as provide structural engineers with a complete and reliable set of automated design aids and construction specification controls, never before available.