

# Investigation of the July 27, 2011 Systems-engineered Metal Building Collapse in San Marcos, TX

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## **1. Executive Summary**

A structural failure investigation was carried out on the systems-engineered metal building that collapsed on July 27, 2010 at 209 Thermon Dr., San Marcos, TX. The building was under construction during the collapse which killed one worker and injured another.

An engineer from the Office of Engineering Services (OES) in the Directorate of Construction (DOC) at OSHA's National Office in Washington, DC visited the incident site on August 8 and 9, 2011 to inspect the collapsed systems-engineered metal building and discuss the circumstances surrounding the collapse with the compliance officer from the Austin Area Office and the general contractor. The inspection included taking measurements of the collapsed systems-engineered metal building, examining the failed connection between the footing and the primary framing columns, collecting test samples of base plates, anchor rods, bolts, washers, and nuts, and taking photographs of the collapsed systems-engineered metal building.

The systems-engineered metal building was designed and manufactured by the Metallic Building Company. The general contractor on the project was Bailey-Elliott Construction of Austin, TX and the subcontractor responsible for the erection of the systems-engineered metal building was Jetika Steel Erectors.

In conjunction with the field observations and laboratory tests, we reviewed the manufacturer's drawings, the installation manual developed by the Metallic Building Company, foundation drawings prepared by the foundation engineer, current construction industry practices applicable to the design, manufacturing and erection of systems-engineered metal buildings, and the 29 CFR 1926 OSHA Construction Standard applicable to the erection of systems-engineered metal buildings.

The engineer's field observations at the incident site revealed that neither temporary bracings necessary for the safe erection of systems-engineered metal buildings nor permanent wall bracings required to resist lateral loads as shown in the manufacturer's drawings were installed.

The laboratory results indicated that the properties of the materials used for the fabrication of the systems-engineered metal building's structural elements and the fasteners used to connect the metal building to the foundation slab satisfied the requirements specified in the American Society of Testing Materials (ASTM) Standard.

We concluded from our investigation that the subcontractor responsible for the erection of the systems-engineered metal building did not follow the guidelines indicated in the manufacturer's drawings and the procedures specified in the installation manual developed by the manufacturer to safely erect and maintain the structural stability of systems-engineered metal buildings during construction.

Had the erector followed the procedures specified in the installation manual developed by the Metallic Building Company with respect to temporary and permanent bracings and had the erector complied with the OSHA regulations pertaining to the erection of systems-engineered metal buildings, he would have avoided the collapse of the systems-engineered metal building and thereby prevented the resulting loss of life and injuries.

## **2. The Incident**

On July 27, 2010 at around 12 p.m., a systems-engineered metal building collapsed at 209 Thermon Dr., San Marcos, TX, killing one worker and injuring another. The building was under construction at the time of the collapse and it was intended to be a new manufacturing building for Thermon Manufacturing Company. Thermon manufactures heat-tracing products that are used in oil, gas and refining industries.

On August 3, 2011, the OSHA Regional Administrator for Region VI asked the Office of Engineering Services (OES) of the Directorate of Construction (DOC) at OSHA's National Office in Washington, DC, to provide engineering assistance in investigating the collapse and determining the causes of the incident.

An engineer from the Office of Engineering Services (OES) in the Directorate of Construction (DOC) visited the incident site on August 8 and 9, 2011 to discuss the circumstances surrounding the collapse with the compliance officer from of the Austin Area office and the general contractor on the project.

The engineer inspected the collapsed building, took measurements of the systems-engineered metal building, examined the failed connection between the footing and the primary frame columns, collected test samples of base plates, anchor rods, bolts, washers and nuts, and took photographs of the systems-engineered metal building collapse.

The systems-engineered metal building was designed and manufactured by Metallic Building Company. The general contractor on the project was Bailey-Elliott Construction of Austin and the subcontractor responsible for the erection of the systems-engineered metal building was Jetika Steel Erectors. Jetika Steel Erectors was hired by Bailey-Elliott Construction to erect the structure.

The DOC's investigation included:

- Review of the manufacturer’s drawings developed by the Metallic Building Company (see Ref. 1).
- Review of the foundation drawings prepared by the foundation engineer (see Ref. 2).
- Examining the photographs obtained from the incident site during our site visit.
- Review of the current industry practices applicable to the design, manufacturing, and erection of systems-engineered metal buildings (Refs. 4-to-13).
- Evaluating the laboratory results of the test samples collected during our site visit in order to determine the actual properties of the material used to manufacture the systems-engineered building components.
- Review of the requirements in 29 CFR 1926 the OSHA Construction Standard applicable to construction of systems-engineered metal buildings (Ref. 3).

### **3. Background Information**

Systems-engineered metal buildings are widely known in the building trades as “pre-engineered buildings”. The Metal Building Manufacturers Association (MBMA), an association of companies engaged in designing, manufacturing and marketing systems-engineered metal buildings, uses the term “metal-building systems” to describe these buildings (see Ref. 11).

Systems-engineered metal buildings are comprised of rigid frames (moment-resisting frames) spanning the short direction of the building; purlins, girts, sidewall bracings to resist lateral loads in the direction perpendicular to the frames; vertical bracings located in endwalls primarily to resist lateral loads acting in the direction parallel to the frames; and roof diaphragm; and a system of horizontal braces that help to distribute loads among the lateral load-resisting elements (see Fig. 1).

Systems-engineered metal buildings are products of steel-building systems manufacturers that are chiefly engaged in the practice of designing and fabricating these structures. Manufacturers that produce these buildings were in the past certified under the American Institute of Steel Construction (AISC) Metal Building Systems Certification Program, AISC FCD-90 (Ref. 11).

The AISC Quality Certification Program served as a pre-qualification system for structural steel fabricators. The purpose of the AISC Quality Certification Program was to confirm to the construction industry, builders, and owners that a certified structural steel fabricating plant has the personnel, organization, experience, procedures, knowledge, equipment, capability, and commitment to produce fabricated steel of the required quality for a steel building (Ref. 11).

On April 8, 2008, the International Accreditation Services (IAS) Accreditation Committee approved the new Inspection Programs for Manufacturers of systems-engineered metal buildings (Ref. 11). This third-party accreditation program for the inspection of systems-engineered metal building manufacturers was based on the requirements of Chapter 17 of the International Building Code (Ref. 4). The program provided code officials with a means to approve the inspection programs of manufacturers involved in the fabrication of systems-engineered metal buildings. The IAS currently administers the systems-engineered Metal Building Certification Program and issues the accreditation certificates (IAS AC472) that are fully endorsed by MBMA.

The three main components of a systems-engineered metal building, i.e., the structural system, the wall system, and the roof system are designed to behave as an integrated system under gravity and lateral loads. The structural components of systems-engineered metal buildings are designed by a licensed professional engineer experienced in the design of these structures (Ref. 11).

In properly functioning conventional buildings, loads are transferred between various building elements by a system of load transfer called a load path. Contrary to the conventional building design, the key factor in systems-engineered metal building design is that the structure must be designed as a system. The members are designed as if they are located in the completed building, with all supports and bracings in place to maintain stability of the structure (Ref. 11).

The following loads are considered in the design of systems-engineered metal buildings (see Refs. 4 & 11):

1. Dead loads due to the actual weight of the building system, such as rigid frames, wall and roof members.
2. Collateral loads due to the weight of additional permanent materials other than the building system, such as sprinklers, mechanical systems, electrical systems, plumbing, partitions, and ceilings.
3. Floor live loads due to loads induced on the floor system by the use and occupancy of the building.
4. Roof live loads due to loads that are produced by workers during maintenance.
5. Snow loads due to the weight of snow, assumed to act on the horizontal projection on the roof of the structure.
6. Seismic loads due to the lateral load acting in any direction on a structural system due to the action of an earthquake.
7. Wind loads due to the load caused by the wind from any horizontal direction.
8. Dynamic live loads due to loads induced by cranes and material handling systems.
9. Thermal loading due to a variation in temperature.

The load transfer from the systems-engineered metal building to the foundation occurs through anchor rods. The design of the foundation and the anchor rods is not the responsibility of the systems-engineered metal building manufacturer (see Ref. 11). Typically the systems-engineered metal buildings manufacturer will specify the quantity, diameter and spacing of anchor rods for a specific condition based on the allowable forces that are to be transferred to the foundation. But, the anchor rod setting, embedment, and foundation reinforcement details are the responsibility of the project engineer. The project engineer designs the foundations for the most critical load effect and thereby completes the final link of the load path to the foundation (Refs. 7, 8, & 11).

The AISC, Code of Standard Practice for Steel Building-Erection (see Ref. 6) requires grouting and leveling (using leveling nuts or leveling plates or shims) during erection to stabilize base plates, align column bases, and for uniform distribution of the column loads to the foundation. Contrary to this practice, columns of a systems-engineered metal building are usually placed



directly on top of concrete foundations. The MBMA common industry practices specify grouting and leveling as *work usually not included in the erection* of systems-engineered metal buildings.

Cast-in-place steel anchor rods are classified as headed, threaded with nut, and hooked (see Ref. 6). The strength of steel anchors depends on material properties, size, edge distance, embedment depth, spacing between steel anchors, and concrete strength of the foundation. The design capacity of an anchor is very sensitive to edge distance. When an anchor rod is placed too close to the edge of a concrete element, it is very difficult to develop the required force. Therefore, to avoid a splitting failure of concrete, adequate edge distance has to be provided.

Hooked anchor rods (J- or L-bolts) made from high strength steel do not develop their full design strength. The AISC (American Institute of Steel Construction) Manual, 13<sup>th</sup> edition, stated that high-strength steels are not recommended for use in hooked bolts because bending with heat might materially alter their strength (see Ref. 6). The AISC Manual specifies that hooked anchor rods should be used only for axially loaded members subject to compression. Hooked anchor rods subjected to tensile loading, as a result of crushing inside the hook, fails by pulling out of concrete before developing its full tensile strength, an undesirable type of failure. The AISC Manual recommends the use of headed anchor rods for tensile loading over hooked anchor rods. Hooked anchor rods are commonly used by contractors because a larger diameter hooked anchor rod is cheaper than a smaller diameter headed rod of equivalent capacity.

The 2009 IBC, International Building Code (Ref. 4), specifies design procedures for anchor rods subjected to tension and shear. The American Concrete Institute Standard, Building Code Requirements for Structural Concrete (ACI 318-08) and Commentary, Appendix D, lists detailed design guides for anchoring steel elements to concrete (see Ref. 5).

Systems-engineered metal buildings are most vulnerable to collapse during erection when all components are not yet installed (Ref. 14). Therefore, it is most important at the time of construction to ensure that all temporary and permanent bracings called for in the installation manuals and manufacturer's drawings are properly installed at all construction stages. Serious

precautions shall be taken by the erectors so that all components of the structure interact with each other to provide the required level of structural stability and safety.

The erection methods used for systems-engineered metal buildings depend on the type and size of the building, the equipment used for erection, the experience level of the crews, and the individual site conditions (Refs. 7-to-12).

Temporary bracings are needed for squaring, plumbing, and securing the structural framing. The AISC manual (Ref. 6) requires that temporary bracings shall be provided wherever necessary to support the loads to which the structure may be subjected during construction and shall be left in place as long as required for safety (see Appendix). Loads during erection of systems-engineered metal buildings include wind loads acting on the exposed framing, impact loads from construction equipment and/or adjacent members while being erected. Not only temporary bracings but also proper tightening of all fasteners is necessary for structural stability during erection.

The ASCE 37-02 (American Society of Civil Engineers Standard - Design Loads on Structures During Construction) states that structures shall be stabilized during construction to resist wind loads with full regard to all intermediate stages of construction (Ref. 13). Systems-engineered metal buildings are designed as an enclosed building under wind loading. However, the projected areas of exposed frames and roof members during construction might be larger than that of an enclosed building, thus receiving more wind load. Therefore, it may be necessary to check the stability of an open structure subjected to wind load during construction. The ASCE 37-02 standard stipulates that for certain hazardous construction operations, it might be appropriate to apply a minimum wind pressure of 10 psf (see Appendix).

Manufacturers in most cases do not furnish erection drawings and they simply cite the variability of the erection procedures, local conditions, and the erector's expertise (Ref. 11). Therefore, it is necessary for the project engineer and the owner to discuss proper erection procedures that address the necessary temporary bracings before the construction document is finalized in order to maintain structural stability during construction (Refs. 7-to-11).

Erection plans show temporary supports such as guys, braces, false work, and cribbing or other elements required for the erection operation. The erector is responsible for furnishing and installing these elements. Some systems-engineered metal building standards and technical manuals explicitly require erection plans for the construction of systems-engineered metal buildings and specify that erection drawings must be implemented by the erector/contractor (Ref. 10). Several systems-engineered metal buildings have collapsed in the past due to inadequate temporary erection bracings (see Ref. 14). Therefore, it is the duty of the general contractor or erector (subcontractor) to prepare a site-specific erection plan to successfully erect systems-engineered metal buildings without collapse, injury and/or death (Refs. 7-to-11).

#### **4. Description of the Collapsed Systems-engineered Metal Building**

The systems-engineered metal building in San Marcos, TX, consisted of four buildings (see Ref. 1). These were: Buildings A, B, C, & D (see Fig. 2). Building A was approximately 300' long and 150' wide. Building B was approximately 76' -10" long and 20' wide. Building C was approximately 54' by 42'. Building D was approximately 35' long and 7'-6" wide.

The structural framing of building A consisted of 11 primary (rigid) frames and 2 standard endwall frames with “beam and post” type construction spanning in the north-south direction (see Fig. 2). Building A was comprised of 10 bays with a bay spacing of 25' and 2 bays with a bay spacing of 24'-8" in the east-west direction. The symmetrical primary frames spanned 150 ft. with an eave height of 24 ft. (see Fig 3). None of the column interior flange braces specified in the manufacturer’s construction drawings (see sheet number R2 in Ref. 1) was installed prior to the collapse of the building.

The rafters of the primary frames consisted of 4 roof beams that were connected using 8 -  $\frac{3}{4}$ "N by 2" long A325 bolts. The rafters were joined to the columns by 14 - 1"N by  $2\frac{1}{2}$ " long, 14 - 1" N by  $2\frac{3}{4}$ " long or 16 -  $\frac{3}{4}$ "N by  $2\frac{1}{2}$ " long A325 bolts (see Ref. 1). None of the

rafter bottom flange braces specified in the manufacturer's construction drawings (see sheet number R3 in Ref. 1) was installed prior to the collapse of the building.

Cold formed Z-section sidewall girts at spacings of 5'-8", 5'-4", and 5'-7" were specified in the manufacturer's construction drawings (see Ref. 1). Some but not all of the sidewall girts were installed prior to the collapse of the building (Fig. 12).

The construction drawings showed for Building A four  $\frac{1}{2}$ " diameter x-braces for the north sidewall (see drawing E9 in Ref. 1), four  $\frac{3}{8}$ " diameter x-braces for the south sidewall (see drawing E10 in Ref. 1), one  $\frac{1}{4}$ " diameter x-brace for the east endwall (see drawing E12 in Ref. 1), and one  $\frac{1}{4}$ " diameter x-brace for the west endwall (see drawing E13 in Ref. 1). The drawings indicated for Building B one  $\frac{1}{4}$ " diameter x-brace for the south sidewall (see drawing E15 in Ref. 1) and for building C one  $\frac{1}{4}$ " diameter x-brace for the north sidewall (see drawing E11 in Ref. 1). These permanent braces were provided by the manufacturer to resist lateral loads. None of these braces was installed prior to the collapse of the building (see Fig. 12).

The roof of the systems-engineered metal building had a low-profile slope of  $1\frac{1}{2}$  -to-12. The manufacturer's drawing indicated  $\frac{1}{4}$ ",  $\frac{5}{16}$ ", &  $\frac{3}{8}$ " diameter x-bracings between the roof framing lines D & E and K & L (see sheet number E5 in Ref. 1). Cold-formed Z-section purlins at a spacing of 5' were specified to support the roof panels. None of the x-braces indicated in the roof framing plan was installed and not all purlins were put in place prior to the collapse of the building (see Fig. 12).

Base plates were fillet welded to the columns of the primary frames by the manufacturer before they were delivered to the site. The columns were connected to the foundation slab using six anchor rods. The posts of the endwalls had fillet welded base plates at their base and were connected to the foundation slab using four anchor rods at the site (see Ref. 1).

## 5. Structural Failure Investigation

The systems-engineered metal building was designed and manufactured by the Metallic Building Company. The company was accredited by the International Accreditation Service, Inc. (see Fig. 4). Accreditation Criteria for Inspection Programs for the manufacturers of systems-engineered metal buildings (AC472) is recognized under Section 1704.2.2 of the 2009 International Building Code (Ref. 4). The Building Code used for the design of the systems-engineered metal building was the 2009 International Building Code (Ref. 4).

The manufacturer's drawings specified the following design criteria (see manufacturer's drawing sheet number E1 in Ref. 1):

- Occupancy Category II
- Roof dead load
  - Superimposed dead load 2.25 psf (Building A)  
2.85 psf (Building B)  
2.58 psf (Building C)  
2.33 psf (Building D)
  - Collateral loads 5.00 psf (Building A)  
0.50 psf (Building B)  
3.00 psf (Building C & D)
- Roof live load 20.00 psf (reduction allowed)
- Snow load
  - Ground snow load ( $p_g$ ) 5.00 psf
  - Snow load important factor (I) 1.00 psf
  - Flat roof snow load ( $P_f$ ) 3.50 psf (Building A)  
5.00 psf (Buildings B, C, & D)
  - Snow exposure factor ( $C_e$ ) 1.00
  - Thermal factor ( $C_t$ ) 1.00
- Wind load
  - Basic wind speed 90 mph

Wind important factor (I)	1.00
Wind exposure category	B
Internal pressure coefficient ( $GC_{pi}$ )	0.18/-0.18

- Seismic load

Seismic design category	A
Soil site class	D (stiff soil)
Mapped spectral acceleration short periods ( $S_s$ )	0.090 g
Mapped spectral acceleration for a 1-second ( $S_1$ )	0.031 g
Design spectral response acceleration ( $S_{ds}$ )	0.096 g
Design spectral acceleration for a 1-second ( $S_{d1}$ )	0.050 g

The Metallic Building Company specified the following notes as a builder/contractor responsibility in the manufacturer's construction drawings (see sheet number E1 in Ref. 1):

- *The Builder is responsible for applying and observing all pertinent safety rules and regulations and OSHA standards as applicable.*
- *The Builder/Contractor is responsible for all erection of the steel and associated work in compliance with the Metal Building Manufacturers drawings. Temporary supports, such as temporary guys, braces, false work and other elements required for erection will be determined, furnished and installed by the erector (AISC Code of Standard Practice Sept. 86 Section 7.91. & Mar. 05 Section 7.10.3).*
- *The metal building manufacturer is not responsible for the design, materials and workmanship of the foundation. Anchor rod plans (F1-to-F5) prepared by the manufacturer are intended to show only location, diameter and projection of the anchor rods required to attach the metal building system to the foundation. It is the responsibility of the end customer to ensure that adequate provisions are made for specifying rod embedment, bearing values, tie rods and other associated items embedded in the concrete foundation, as well as foundation design for the loads imposed by the Metal Building System, other imposed load, and the bearing capacity of the soil and other conditions of*

*the building site (MBMA 06 Sections 3.2.2. and A3).*

- *Material properties of steel bar, plate and sheet used in the fabrication of built-up structural framing members conform to ASTM A529, ASTM A 572, ASTM A1101 SS, or ASTM A1011 HSLAS with a minimum yield point of 50 ksi.*
- *Material properties of hot rolled structural shapes conform to ASTM A992, ASTM A529, or ASTM A572 with a minimum specified yield point of 50 ksi.*
- *Hot rolled angles, other than flange braces, conform to ASTM A36 minimums.*
- *Hollow structural shapes conform to ASTM A500 grade B; minimum yield point is 42 ksi for round HSS and 46 ksi for rectangular HSS.*
- *Material properties of cold-formed light gage steel members conform to grade 55, with a minimum yield point of 55 ksi.*
- *All bolted joints with A325-09 Type 1 bolts are specified as snug-tightened joints in accordance with the “Specification for Structural Joints Using ASTM A325 or ASTM A490 Bolts, June 30, 2004.” Pretensioning methods, including turn-of-nut and calibrated wrench are NOT required.*
- *Anchor rods are A36 or A307 material unless noted otherwise.*
- *X-Bracing is to be installed to a taut condition with all slack removed. Do not tighten beyond this state.*
- *This project is designed using manufacturer’s standard serviceability standard.*
- *This metal building system is designed as enclosed.*

The installation manual developed by the Metallic Building Company stated that (see Ref. 7):

- *The construction drawings show the buildings as engineered and fabricated according to the information given to the Manufacturer. The building construction drawings will always govern with regard to construction details and specific building parts. However, it may be necessary for the engineer of record (not the Manufacturer) to prepare installation sequences drawings.*
- *The Manufacturer disclaims any responsibility for damages that result from use of the installation manual since the actual installation operation and conditions are beyond the Manufacturer's control. Only experienced, knowledgeable installers with trained crews and proper equipment should be engaged to do installation.*
- *It is emphasized that the Manufacturer is only a manufacturer of metal buildings and components and is not engaged in the installation of its products. Opinions expressed by the Manufacturer about installation practices are intended to present only a guide as to how the components could be assembled to create a building. Both the quality and safety of installation and the ultimate customer satisfaction with the completed building are determined by the experience, expertise, and skills of the installation crews as well as the equipment available for handling the materials.*
- *The Metal Building Manufacturer's Association, "CODE OF STANDARD PRACTICE" shall govern with respect to fabrication tolerances, installation methods, and all field work associated with the project in question. The installer should familiarize himself with the contents of this document.*

The following installation procedures were specified as a general guide in the installation manual developed by the Metallic Building Company (see Ref. 7):

- *Plan to install a braced bay first.*
- *It is the responsibility of the installer to provide temporary installation bracing until the structure is complete.*



- *Remove temporary bracing only after all paneling has been installed.*
- *Install wind bracing. Diagonal bracing in metal buildings is critical! Additional temporary bracing is needed to stabilize the structure during installation. All bracing should be installed to a taut condition removing all slack.*
- *Finish installing flange braces (i.e., rafter flange braces) to purlins as soon as the purlin has been installed.*

The manufacturer designed the primary frames assuming hinge-connections at column bases, i.e., no bending moment was assumed to be transferred from the columns to the foundation. The manufacturer's drawings specified ASTM A325 bolts to connect the rafters to the columns of the primary frames. Permanent x-braces were specified in the manufacturer's drawings to resist lateral loads (see Ref. 1). However, our site visit revealed that neither the permanent braces called for in the drawings nor the temporary bracings specified in the installation manual were put in place at the time of the collapse of the systems-engineered metal building.

The unfactored reactions due to the service loads specified in the design criteria for the primary and endwall frames were shown in the construction drawings (see sheet numbers F6 to F7 in Ref. 1). The construction drawings stated that it is the responsibility of the foundation engineer to apply the load factors from the applicable building code, in order to design the foundation. The foundation was a post tensioned slab on grade. A36 or A307 anchor bolts were recommended to connect the columns to the foundation (see Ref. 1).

The sizes of the base plates of the primary framing columns specified in the manufacturer's drawings were 1'-4" long by 8" wide, 1'-3" long by 8" wide, 1'-2" long by 8" wide, and 1'-1" long by 8" wide. The thicknesses of the base plates indicated in the manufacturer's drawings were 0.625" and 0.750". Six anchor rods having diameters of 1" or  $\frac{3}{4}$ " and with a minimum projection of 3" above the slab on grade were specified to anchor the base plates of the primary framing columns to the foundation. A 4" center to center spacing of anchor rods was specified in the drawings (see manufacturer's drawing F4, details B, C, D, & E in Ref. 1). The foundation engineer specified a minimum length of 18" for the anchor rods (see Ref. 2). The minimum center-to-center spacing of cast-in-place anchors required by ACI 318-08 (see Ref. 5) is  $4d_a$  ( $4d_a$

= 4", where  $d_a = 1.0$ " is the diameter of anchor rods used). Therefore, the 4" spacing provided by the foundation engineer for the anchor rods was found to be adequate.

The sizes of the base plates of the endwall framing posts (columns) indicated in the manufacturer's drawings were 10.5" long by 6" wide and 8.5" long by 6" wide. The thickness of the base plates was 0.375". Four anchor rods having a diameter of 5/8" and a minimum projection of 2" above the slab on grade were specified to anchor the base plates of the endwall framing posts to the foundation. The manufacturer's drawing showed 3" center to center spacing of anchor rods (see drawing F4, details H, K, & J in Ref. 1). The minimum center-to-center spacing of cast-in-place anchors required by ACI 318-08 (see Ref. 5) is  $4d_a$  ( $4d_a = 2.5$ ", where  $d_a = 5/8$ " is the diameter of anchor rods used). Therefore, the 3" spacing provided by the foundation engineer for the anchor rods was found to be adequate.

The construction drawings indicated an edge distance of 4" to the center of the anchor rods in the north-south direction for the primary framings. The drawings showed an edge distance of  $2\frac{1}{2}$ " to the center of the anchor rods in the north-south direction and an edge distance of 4" to the center of the anchor rods in the east-west direction for the endwall framing. The minimum edge distance required for untorqued cast-in-place anchors (J-bolts are not likely to be torqued) by ACI 318-08 is the same as the minimum concrete cover required for reinforcement. The minimum concrete cover required for reinforcement by ACI 318-08 for concrete exposed to earth is 2". Therefore, the edge distances provided for the anchor rods were found to be adequate.

The foundation drawings called for post tensioned mat foundation, a minimum concrete cylinder compressive strength at 28 days of 3000 psi, and tendons to be 1/2" in diameter - 270 ksi low relaxation strands. The mat foundation was a 6" thick post tensioned slab monolithically cast with 12" wide by 24" deep post tensioned beams spaced approximately 25' center to center in the east-west direction and approximately 18', 25' & 32' in the north-south direction (see foundation drawings F01 & F02 in Ref. 2).

We observed during our site visit that the anchor rods of the north primary framing columns pulled out from the foundation with insignificant breakout of the portion of the surrounding

concrete (see Fig. 13). The anchor rods at the south primary frame columns were observed to be failed in tension. Fig. 14 shows when a column was being cut to obtain samples that can be used for testing the plates and fillet weld connections. The anchor pullout mode of failure in the north primary frame columns was believed to be caused by the lateral torsional buckling of the rafters that had no flange braces followed by the failure of the south primary frame columns at their base (see Figs. 15-to-18).

OSHA regulations for steel erection require a minimum of four bolts in all columns except for “posts”. Our site visit revealed that there were six bolts for the primary framing columns and four anchor bolts for the endwall posts. The OSHA Standard states that construction loads shall not be placed on any steel structural frame work unless such frame work is bolted, welded or otherwise adequately secured and these loads shall be placed within 8 feet (25m) of center line of the primary support member. Our site visit confirmed that there were some unsecured or unfastened purlins between the primary frames on the rafters (see Fig. 19).

Rigid frames of systems-engineered metal buildings offer little lateral resistance perpendicular to their plane unless fixed at their bases. Stability in this direction is provided by sidewall permanent bracings consisting of steel rods or cables. Our site visit revealed that neither temporary bracings nor permanent wall bracings shown in the manufacturer’s construction drawings were installed. Figures 5-to-12 showed the progress of the construction of the systems-engineered metal building without temporary and permanent bracings. The 150 ft.-long rafters without intermediate vertical support, no bottom flange braces, and no cross bracing at roof level were marginally stable under dead weight alone. A slight lateral load that may have occurred at any time during erection was sufficient to create lateral torsional buckling of the rafters and thereby the collapse of the rigid frames (see Ref. 11).

It was believed that the rafters with no flange braces and no temporary bracings laterally buckled and caused one or more south side columns of the primary framing to tilt out in the direction of the west side, thus leading to the breaking of the simple non-moment resisting connection at the base of the columns (see Fig. 18). The lateral displacement of the rafters may have been caused by lateral load, uplift from wind, or/and impact load from equipment or adjacent members while

being erected. Once one of the columns failed at its base, then the other columns on either side of the failed column located on the south side of the building buckled and snapped their base connections leading to the pullout of the anchor bolts in the north side columns (see Figs. 15-to-17). This failure indicated that the erector did not follow the procedures stated in the installation manual provided by the manufacturer to the general contractor/erector to safely erect the systems-engineered metal buildings. Had the erector followed the procedures given in the installation manual and the manufacturer's drawings with respect to temporary and permanent bracings, he would have avoided the collapse of the systems-engineered metal building.

Additionally, the AISC manual (see Ref. 6) and the OSHA Safety and Health Standards for the Construction Industry, 29 CFR 1926 (see Ref. 3) stated that structural stability shall be maintained at all times during the erection process. The erector failed to ensure the stability of the structure during construction as stipulated in the AISC manual and the OSHA Safety and Health Standards for the Construction Industry.

## **6. Conclusions**

Based on our investigation, we conclude that:

1. The collapse during construction of the systems-engineered metal building occurred because of the lack of temporary bracings in the east-west direction on the north and south sides.
2. Structural stability of the systems-engineered metal building was not maintained during the erection process.
3. The contractor failed to follow the erection procedures recommended by the manufacturer of the systems-engineered metal building, a copy of which was provided to the contractor.

## 7. References

1. Metal Building Company Manufacturer's Drawings. Sheet Numbers E1-E41, R1-R16, & F1-F8.
2. Metal Building Foundation Drawings (Shop drawing and details). Sheet Numbers F01-F04.
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## 8. Figures

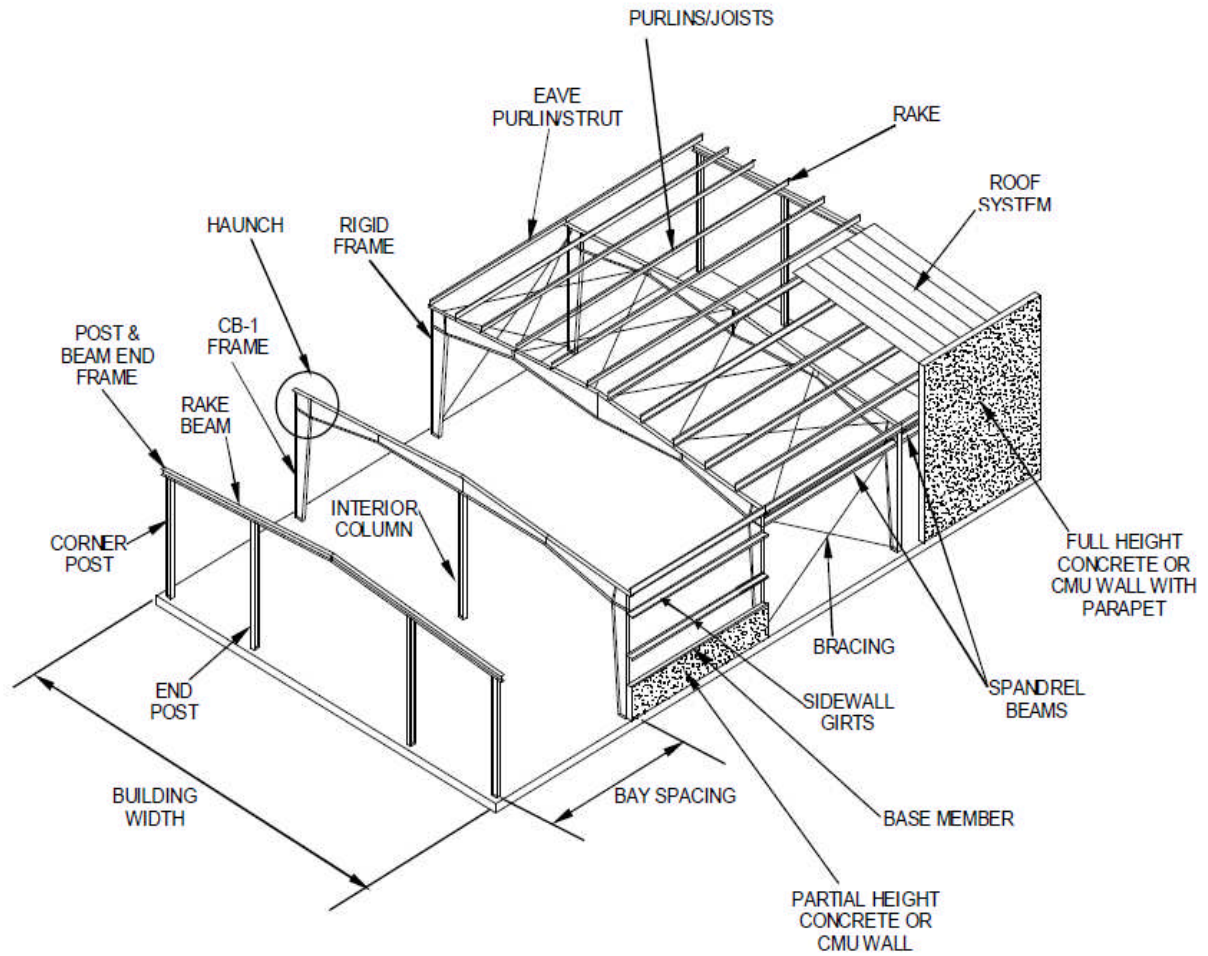
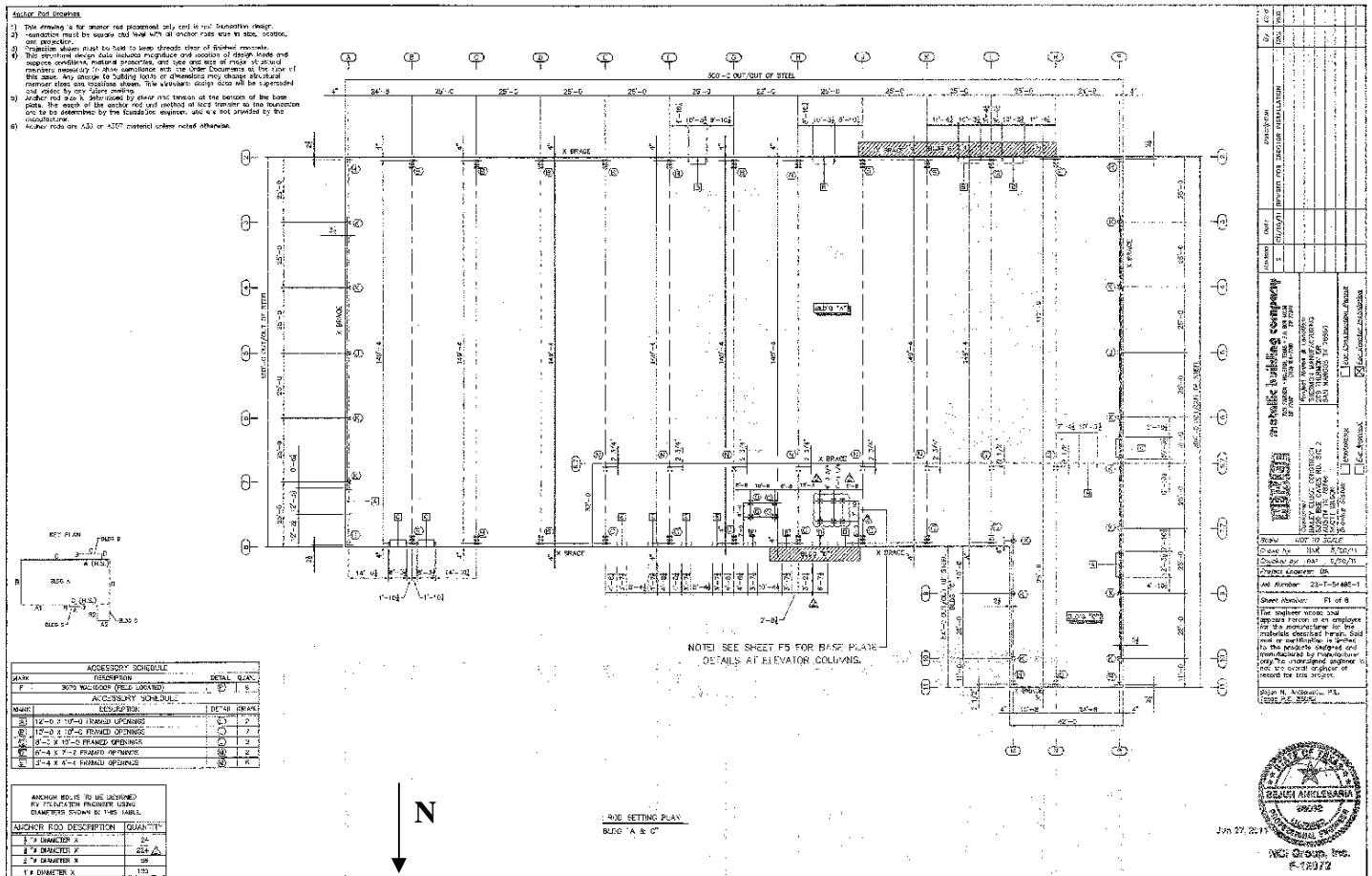


Fig. 1 Typical components of a systems-engineered metal building (source VP Buildings Hardwall Application Guide - Ref. 15).





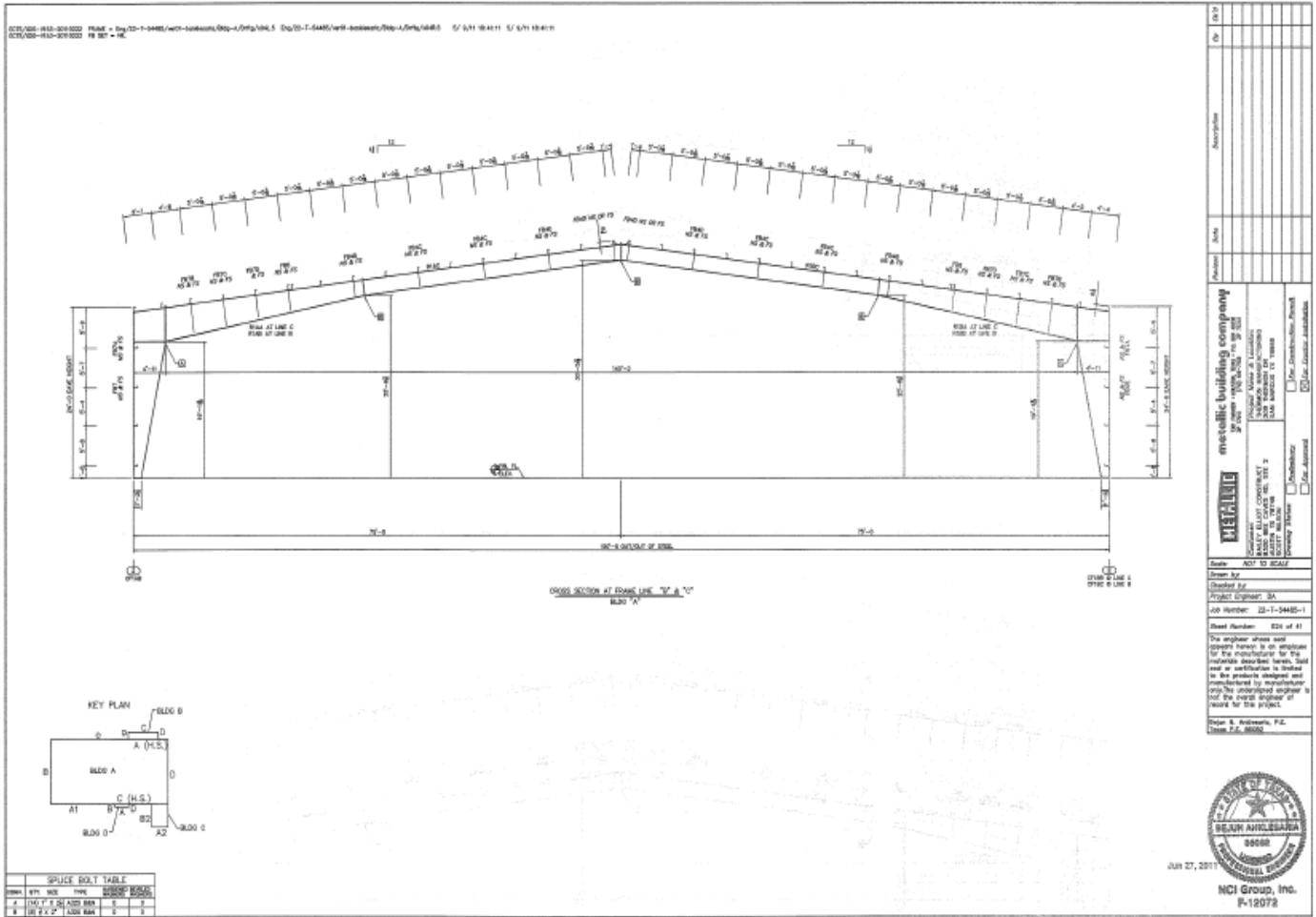


Fig. 3 Typical Primary Frame for Building A (see Ref. 1).

International Accreditation Service  
**CERTIFICATE OF ACCREDITATION**

*This is to signify that*

**NCI BUILDING SYSTEMS, INC.**

7301 FAIRVIEW  
HOUSTON, TEXAS 77041

Inspection Program for the Manufacture of Metal Building Systems MB-116

has demonstrated that its in-plant inspection program for Part A-Fabrication of Structural Weldments and Cold-formed Products Requiring Welding, Part B-Fabrication of Cold-formed Products Not Requiring Welding, and Part C-Design of Metal Building Systems is in compliance with the International Accreditation Service, Inc., Accreditation Criteria for Inspection Programs for Manufacturers of Metal Building Systems (AC472) and is recognized under Section 1704.2.2 of the 2000, 2003, 2006 or 2009 *International Building Code*®, commencing August 7, 2010; expiring August 6, 2011.

Fabrication inspection procedures covered by this certificate are conducted in accordance with the fabricator's approved quality control manual. Periodic plant inspections are conducted by Bucher, Willis & Ratliff Corporation (AA-586), at 7301 Fairview, Houston, Texas, to monitor the fabricator's quality management system verifying continual compliance with the requirements as listed in the above scope of accreditation. Accreditation is limited to the specified inspections related to the fabrication processes and procedures only. Accreditation does not cover the product, or the design or performance characteristics of the fabricated product.

  
Patrick V. McCullen  
Vice President



  
C. P. Ramani, P.E.  
President

This accreditation certificate supersedes any IAS accreditation certificate bearing an earlier date. The certificate becomes invalid upon suspension, cancellation or revocation of accreditation. See the IAS Accreditation Listings on the web at [www.iasonline.org](http://www.iasonline.org) for current accreditation information, or contact IAS directly at (562) 695-0541.

Print Date: 08/06/2010  
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Fig. 4 Metallic Building Company-Certificate of Accreditation.



Fig. 5 Primary Frame Column being Hoisted to be Erected.





Fig. 6 Primary Frame Column being Erected.



Fig. 7 Primary Frame Column being Bolted to the Foundation Slab.



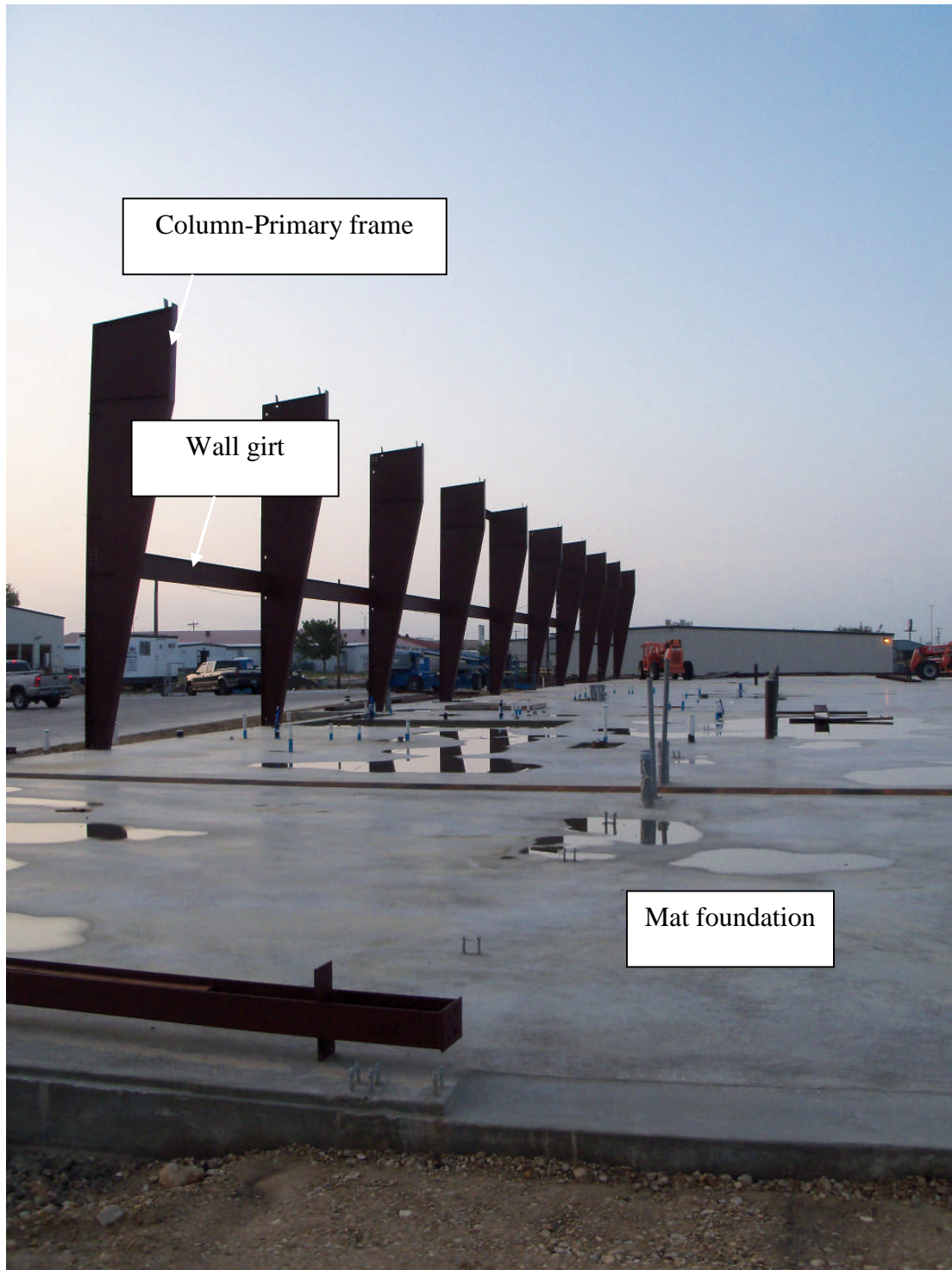


Fig. 8 Columns of the North Sidewall during the First Phase of the Erection of the Systems-engineered Metal Building.

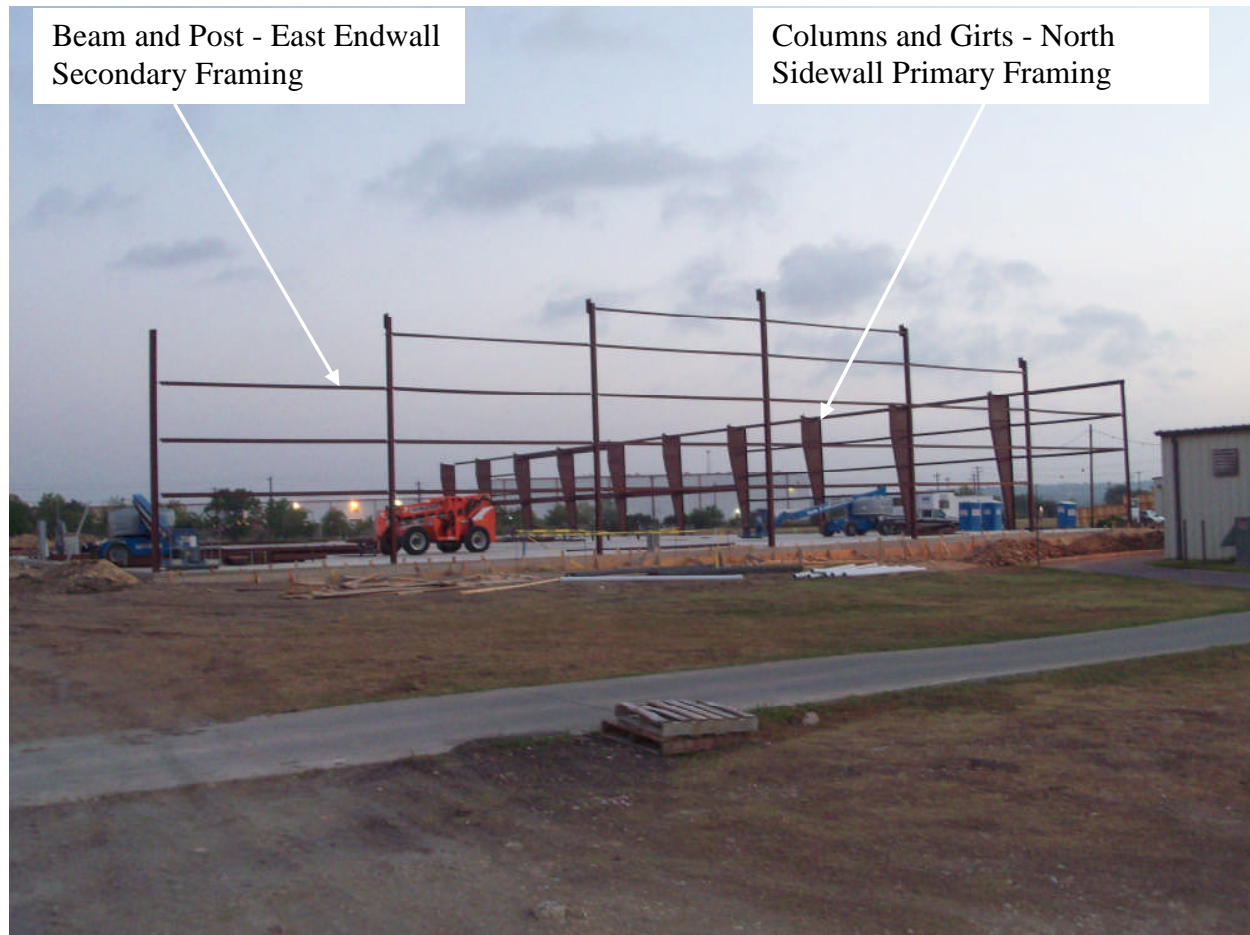


Fig. 9 North Sidewall and East Endwall Framings.



Fig. 10 Columns of North and South Sidewalls and East Endwall Framing.



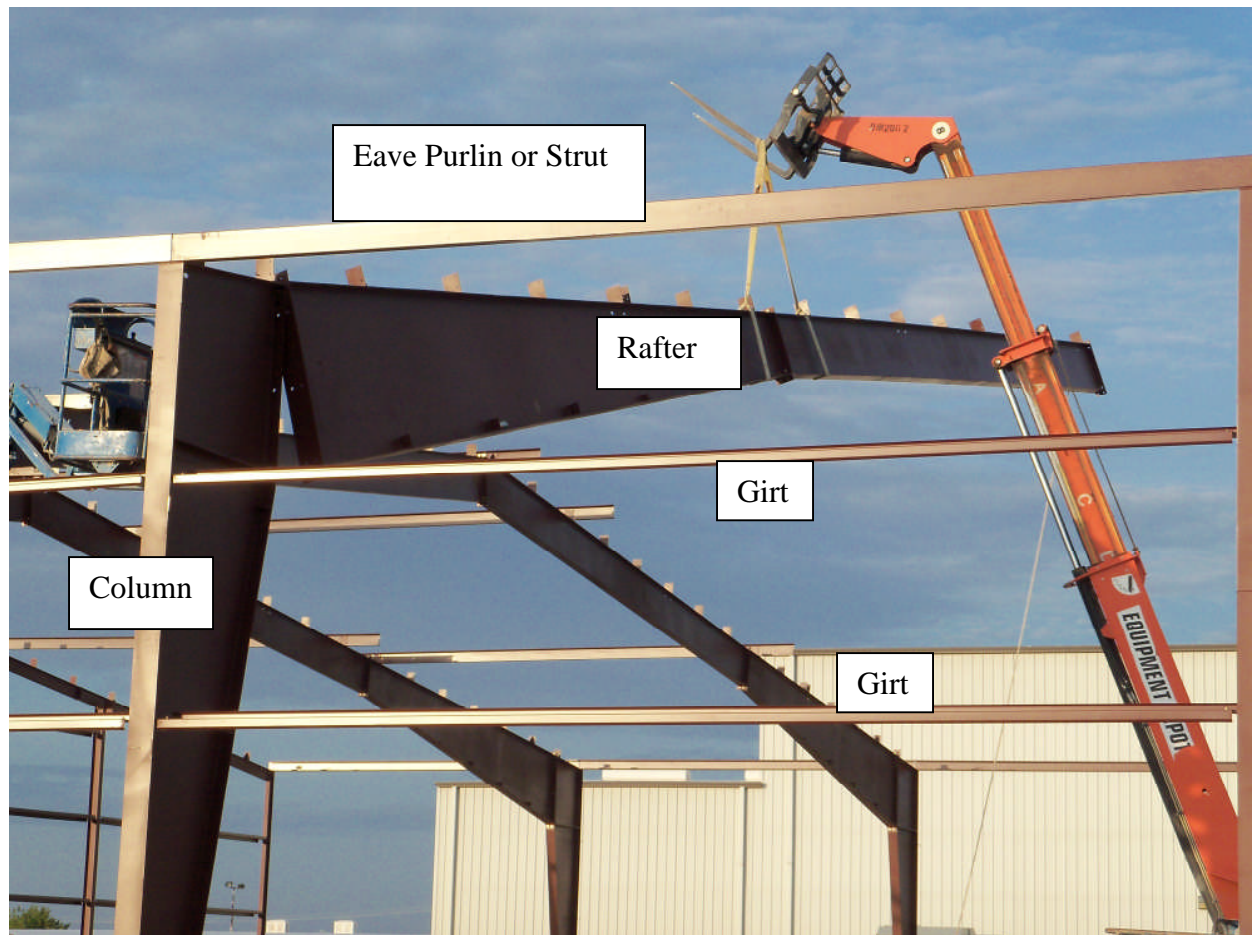


Fig. 11 Rafter being Connected to a Primary Frame Column.



Fig. 12 The Systems-engineered Metal Building before Collapse.



Fig. 13 North Sidewall Column Anchor Pullout Failure.





Fig. 14 Primary Frame Column being Cut for Testing.

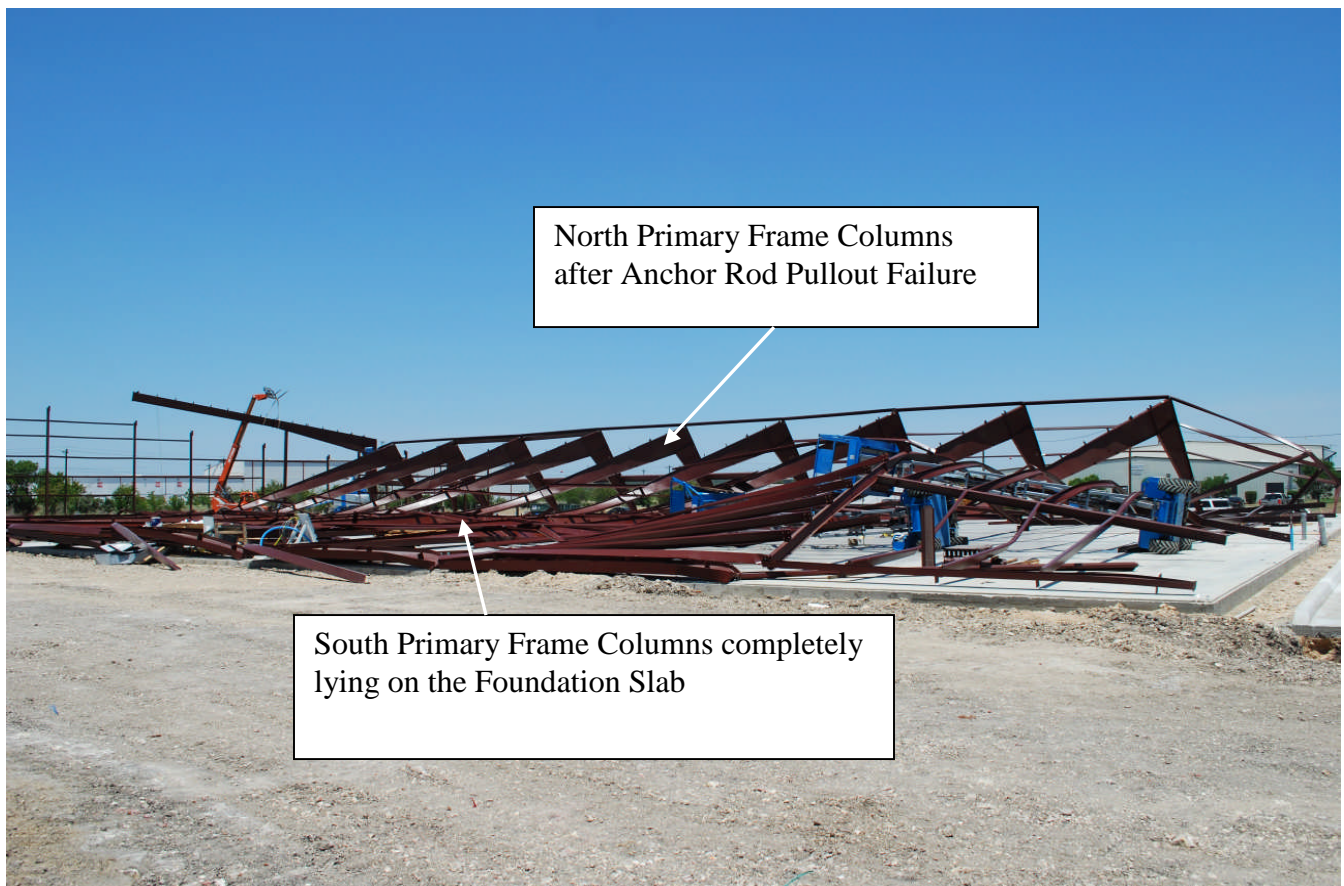


Fig. 15 The Systems-engineered Metal Building after Collapse.



Fig. 16 North Sidewall Columns Anchor Pullout Failure.





South Sidewall Columns  
lying one over the other

Fig. 17 South Sidewall Columns after Collapse.



Fig. 18 North Sidewall Columns and rafters after Collapse.



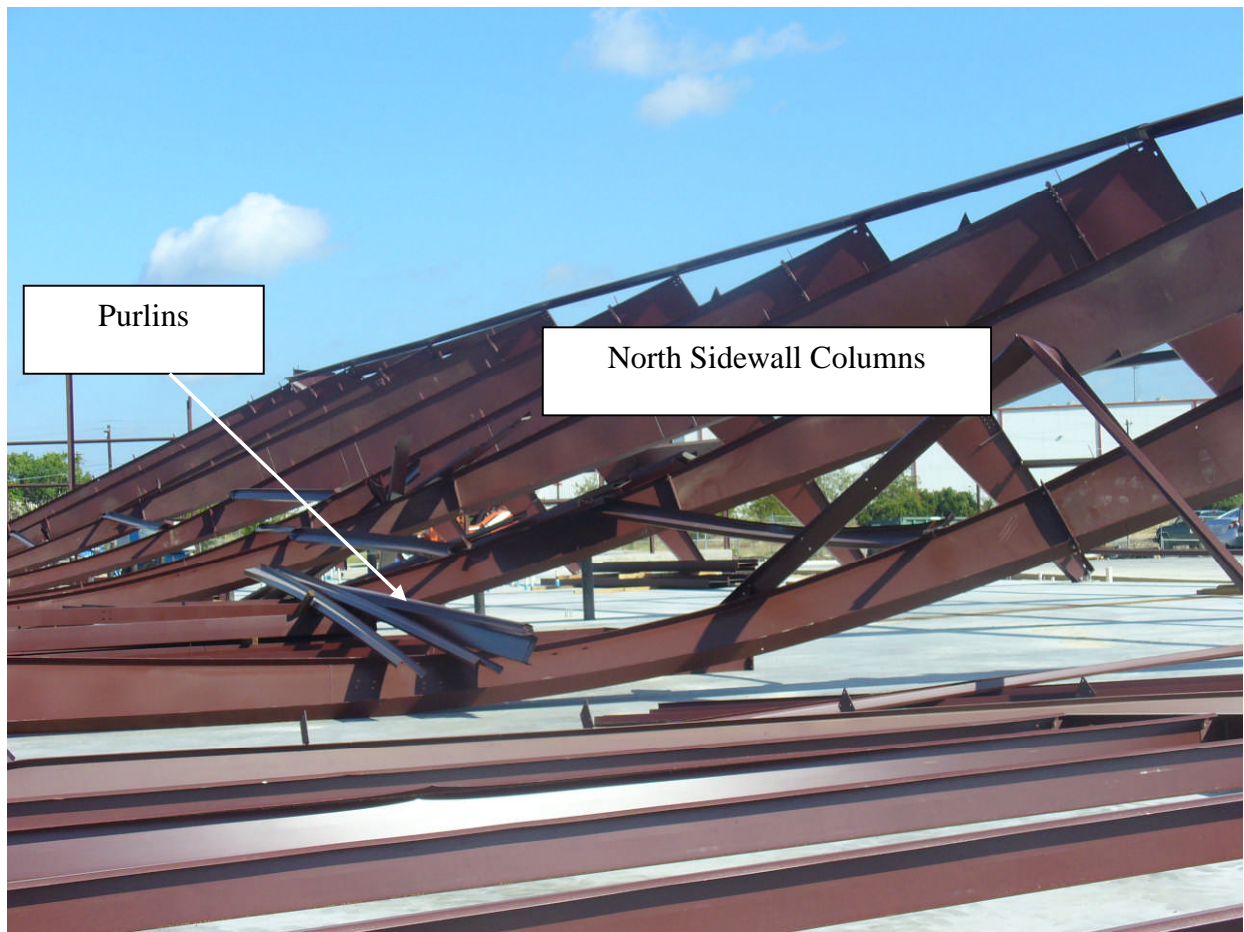


Fig. 19 Unfastened or Unsecured Purlins Lying on the Rafters.

## 9. Appendix

### M4. ERECTION

#### 1. Alignment of Column Bases

*Column* bases shall be set level and to correct elevation with full bearing on concrete or masonry.

#### 2. Bracing

The frame of steel skeleton buildings shall be carried up true and plumb within the limits defined in the AISC *Code of Standard Practice for Steel Buildings and Bridges*. Temporary bracing shall be provided, in accordance with the requirements of the *Code of Standard Practice for Steel Buildings and Bridges*, wherever necessary to support the loads to which the structure may be subjected, including equipment and the operation of same. Such bracing shall be left in place as long as required for safety.

#### 3. Alignment

No permanent bolting or welding shall be performed until the adjacent affected portions of the structure have been properly aligned.

#### 4. Fit of Column Compression Joints and Base Plates

Lack of contact bearing not exceeding a gap of  $\frac{1}{16}$  in. (2 mm), regardless of the type of *splice* used (*partial-joint-penetration groove welded* or bolted), is permitted. If the gap exceeds  $\frac{1}{16}$  in. (2 mm), but is less than  $\frac{1}{4}$  in. (6 mm), and if an engineering investigation shows that sufficient contact area does not exist, the gap shall be packed out with nontapered steel *shims*. Shims need not be other than mild steel, regardless of the grade of the main material.

#### 5. Field Welding

Shop paint on surfaces adjacent to *joints* to be field welded shall be wire brushed if necessary to assure weld quality.

Field welding of attachments to installed embedments in contact with concrete shall be done in such a manner as to avoid excessive thermal expansion of the embedment which could result in spalling or cracking of the concrete or excessive *stress* in the embedment anchors.

#### 6. Field Painting

Responsibility for touch-up painting, cleaning and field painting shall be allocated in accordance with accepted local practices, and this allocation shall be set forth explicitly in the design documents.

#### 7. Field Connections

As erection progresses, the structure shall be securely bolted or welded to support the dead, wind and erection *loads*.

### M5. QUALITY CONTROL

The fabricator shall provide *quality control* procedures to the extent that the fabricator deems necessary to assure that the work is performed in accordance with this Specification. In addition to the fabricator's quality control procedures, material and workmanship at all times may be subject to inspection by qualified inspectors representing the purchaser. If such inspection by representatives of the purchaser will be required, it shall be so stated in the design documents.

## STANDARD

**6.0 ENVIRONMENTAL LOADS**

The basic reference for computation of environmental loads is the 1995 edition of ASCE 7. The requirements of ASCE 7-95 shall be applied except as modified herein.

When an environmental loading is contained in another document acceptable to the authority having jurisdiction, written to address a specific material or method of construction, the more applicable document shall be permitted to be followed.

**6.1 Importance Factor**

During construction, the importance factor,  $I$ , shall be 1.0 for all environmental loads, regardless of what the importance factor is for the completed structure.

**6.2 Wind**

Except as modified herein, wind loads shall be calculated in accordance with procedures in ASCE 7-95.

Design wind pressures shall be based on design velocities calculated in accordance with Section 6.2.1, without increases to meet minimum design wind loading requirements of ASCE 7-95.

**6.2.1 Design Velocity**

The design wind speed shall be taken as the following factor multiplied by the basic wind speed in ASCE 7-95:

Construction Period	Factor
less than 6 weeks	0.75
6 weeks to 1 year	0.8
1 to 2 years	0.85
2 to 5 years	0.9

## COMMENTARY

**C6.0 ENVIRONMENTAL LOADS**

This section deals with special issues of construction and temporary structures for which the basic procedures of ASCE 7-95 are to be modified.

The objective of this standard is to provide a level of safety during construction that is comparable to that of the completed structure. To achieve this, the probability of a load exceeding the factored nominal construction load during the construction period should be roughly the same as that of a load exceeding the factored nominal design load during the projected life of the completed structure.

Standards and other documents applicable to specific materials or methods of construction have been developed and are recognized and used extensively (e.g., AASHTO 1996; CALTRANS 1989; MCAA 2001).

**C6.1 Importance Factor**

The importance factor is 1.0 for all environmental loads during construction, regardless of the occupancy after construction. During construction, the primary occupancy of a building is by construction personnel. As such, the risk to loss of human life is comparable to that for Category II buildings as defined in ASCE 7-95.

**C6.2 Wind**

Structures shall be stabilized during construction to resist the wind loads specified in this section with full regard to all intermediate stages of construction.

Information and guidance have been lacking in the United States on the selection of wind speeds and force coefficients on structures during construction (Ratay 1987). Limited research and development have been performed for the purpose of this standard (Boggs and Peterka 1992; Rosowsky 1995).

If local conditions so dictate, and for certain hazardous construction operations, it might be appropriate to apply a minimum wind pressure, such as 10 psf (0.48 kN/m<sup>2</sup>), to design.

**C6.2.1 Design Velocity**

Wind provisions are established such that  $(1.4)^{0.5} \times$  the construction design wind velocity should have the same likelihood of being exceeded in the construction period (say 1 to 2 years) as  $(1.4)^{0.5} \times$  the 50-year mean recurrence interval design wind does in a 50-year period. The reduced construction period velocity factors have been developed to achieve this objective (Boggs and Peterka 1992; Rosowsky 1995).