STRUCTURAL DESIGN OF THE NEW BOSTON GARDEN ROOF

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SUMMARY

The structural design of the steel-framed 300 ft. x 460 ft. (91m x 140m) singly curved roof of the New Boston Garden Arena is described.

The long span engineering challenge includes consideration of the existing Boston Garden located directly to the south of the proposed building, an active elevated expressway ramp located 8 feet to the north, coordination with a proposed below grade expressway ramp to the east and the ongoing construction of a 2,000 car, 5-level below grade parking garage below, topped by a commuter rail train station. The proposed structural solution must solve the many constraints of the site while matching the articulated geometry that was developed by the Architect to create a signature building for the Owner.

Special features of the roof include a tall mast, a long "wing" element, deep gutters and a section cantilevered 31 ft. (9.5m). Typical roof construction includes steel deck on purlins on steel trusses spanning 296 ft. (90m).

Exterior loadings due to snow and wind were developed with the aid of the wind tunnel consultants. Other design loads included earthquake, temperature change, hung dead and live loads, and special loads such as a central scoreboard and a suspended grid level for catwalks, spotlights, circus rigging and special show lighting and speakers. Trusses were designed for up to 18 load cases.

The final structural framing design is described including steel trusses, truss connections, purlins, lateral bracing system, deflections and camber, probable savings due to use of LRFD for truss design, and steel truss erection considerations.

INTRODUCTION

LeMessurier Consultants are the structural engineers for the proposed New Boston Garden, an enclosed arena structure which will seat 20,000 persons for ice hockey, basketball, the circus, ice shows and other concert and performance events. The New Boston Garden Corporation is the owner, and the architectural design is by Ellerbe Becket Architects, Kansas City. Construction has not yet begun.

OVERALL GEOMETRY

The New Boston Garden has overall plan dimensions of 300 ft x 460 ft, (91m x 140m) with a convex curved roof having a high point 160 ft (49m) above exterior grade and eaves 18 ft (5.5m) lower. The roof shape is a low-rise barrel vault having a uniform radius of 634 ft (193m). The bottom chord level of the main roof trusses is 96 ft (29m) above the arena floor. Deep gutters are provided near the eaves at each side of the roof, and special measures are designed to prevent snow sliding, which would be very hazardous to motorists on an adjoining expressway and to pedestrians. A prominent architectural feature is an 80 ft. (24m) tall mast near the north edge of the roof.

ROOF STRUCTURAL FRAMING DESCRIPTION

The arena structure and its roof are framed in structural steel. Most of the roof area is supported on ten 30 ft (9.2m) deep segmented top chord trusses, at 40 ft (12.2m) on center, spanning 296 ft (90m) c./c. of columns. See figures 1, 3 and 4. Steel purlins at a spacing of 10 to 10.75 ft (3 to 3.3m) span between trusses and carry a 3-inch (76mm) deep acoustical galvanized steel deck, insulation and roofing. Deck is 18 or 20 gage thickness, based on load. Two 29 ft (8.8m) deep longitudinal trusses interconnect the main transverse trusses, to provide bracing and additional rigidity. In-plane diaphragm bracing is provided at the top chord level, also shown in Figure 1. At the bottom chord elevation of the main trusses, called the Grid/Catwalk level, there is a grid of horizontal beams at 20 to 21 ft (6.1 to 6.4m) on center, a system of catwalks, and a large central hung scoreboard. See Figure 2 and 3. The uppermost ring of arena seating, called the Press Ring, is also hung from the Grid/Catwalk level. At the southeast corner of the roof a large section of the framing cantilevers 31 ft. (9.5m).

ROOF DESIGN LOADS

Gravity Loads

These include dead loads of all permanent construction, design live loads, special loads at Grid/Catwalk level, and roof snow load.

Live Loads. Catwalk live load of 30 psf was used, plus allowances for lighting, speakers and spotlights. Press Ring live load is 80 psf including a partition allowance. An allowance of 3 psf was provided, as an overall hung load, to allow for banners, miscellaneous piping and ducts. A central scoreboard weighing 40,000 lbs. (178 KN) was assumed. The Grid/Catwalk level framing is designed to resist a hierarchy of possible loads from such sources as circus rigging and special concert or show hung lighting and speaker grids. For larger areas, a total hung live load of 20 psf was used. For individual beams, concentrated live loads were applied, up to 5,000 lbs., in a number of possible directions.

Snow Loads. The companion paper by Irwin and Gamble, 1992, provides the basis for the roof design snow loads. These are based on a 50-year recurrence interval and a 1.1 building importance factor. Drifting was carefully considered. The gutters were assumed to be filled with heavy wet snow, for snow load design cases. Design snow load used for roof purlins is shown in Figure 5a, and for a representative truss in Figure 5b. A minimum uniform snow load of 30 psf (1.44 KN/m^2) on horizontal projection was used in conformance with the Massachusetts Building Code, even when the wind tunnel study would have allowed less.

Wind Loads

The wind tunnel report for this project, Kochanski and Irwin, 1990, provides the basis for the roof design wind loads. These are based on a 100-year recurrence interval. For the roof purlin design, two opposite extreme design wind pressure diagrams were used, one for negative pressure (uplift) and one for positive pressure (downward). See Figures 6a and 6b. For truss design, four separate design wind load distribution patterns were used, based on the wind tunnel study. The effects of truss dynamic response, arena internal pressure and adjacent buildings were included. The four patterns are: maximum overall uplift, maximum unbalanced wind, maximum positive pressure south half, and maximum positive pressure north half. For designing the in-plane bracing system and longitudinal bridging trusses, the Massachusetts Code lateral wind load was applied in both north-south and east-west directions.

Earthquake Loads

Design earthquake loads were in conformance with the Massachusetts Building Code. Base shear V is 0.333 KCSW. Earthquake loads did not control the design of the purlins or main trusses. Some parts of the in-plane roof bracing system, the Grid/Catwalk level lateral bracing, and the longitudinal bracing trusses were controlled by load combinations with earthquake.

Temperature Loads

The structure is designed for a temperature rise or fall of 60 degrees F. (33.3 deg. C.)

DESIGN OF STRUCTURAL ELEMENTS

Purlin Design

The AISC allowable stress design (ASD) method was used, with these three load combinations: (1) D + L + S, (2) 0.75 (D + L + S + WP), and (3) 0.75 (0.67D-WN). (WP = positive wind, WN = negative wind.) Due to the roof curvature, purlins are oriented with their webs generally non-vertical, along radial planes. Purlins will have lateral bending and sweep deflection under self-weight. Where the calculated sweep exceeded about 0.33 inch (8.5mm), the size was revised or mid-span braces were added. Most purlin sizes were controlled by the third load combination, although the load combination (1) total deflection was also limited to about span/330, which sometimes controlled. The allowable compressive stress for the uplift case of combination (3) was determined using equations 6.11 and 6.12 of the SSRC Guide, Johnston, 1976, and a "factor of safety" of 0.75 x 1.9 = 1.425. Most purlin sizes are W18 and W21 rolled shapes, from W18 x 46 and W21 x 44 to W21 x 68. Heavier sizes are for purlins supporting hung catwalk loads.

Main Truss Design

Truss Geometry is shown in Figure 4. The top chord is to be of straight segments following the roof curvature. Truss depth at each end is 14.2 ft (4.3m). Spacing of vertical web members is 21.2 ft (6.4m), therefore some diagonal web members are over 36 ft (11m) long. The top and bottom chords are rolled W-shapes, oriented with their flanges in vertical planes, like an 'H'. Web members are also rolled W-shapes, with flanges in vertical planes.

Truss Features. At the north end, the top chord must cantilever to support a wing-like architectural feature which extends the full length of the roof. This cantilever is of varying length. Truss chord sizes vary from W14 x 99 to W14 x 370, while web members vary from W14 x 30 to W14 x 211. Both ASTM A36 and ASTM A572-grade 50 steel will be used. All field connections will include gusset plates and high strength ASTM A490 bolts, and some gusset plates will be shop welded to the chord members. Examples of truss connection details are shown in Figure 4. The weight of a typical truss is about 93 tons. (827 KN). It has a first mode natural frequency of about 1.9 Hz. Dead load deflections are: 3.56 inch vertical at mid-span and 1.30 inch horizontal at one end (1 inch = 25.4mm). Total dead plus live load deflections are: 7.69 inch vertical at mid-span and 2.78 inch horizontal at one end. The trusses will be cambered. Each truss member is checked for the worst case of eight load combinations.

Truss Design Method. The ASCE ASD method has thus far been used for designing the main trusses. The LRFD method may be used in lieu of ASD, in order to reduce truss weight. Based upon an exploratory study, a saving in steel weight of 10 to 12 percent may be achievable. Ten load combinations have to be checked. If the LRFD method is used, we will use a factor of 1.3, rather than 1.2, on dead load for the combinations of only gravity load. We deemed the AISC dead load factor of 1.2 not conservative enough for these important, non-redundant members. No two of the trusses are identical, due to variations in loading and the geometry of the north end cantilever.

Truss Erection. A study was made of truss erection, and a detailed possible erection scheme is outlined on the structural drawings. Please refer to Figure 7. In essence, the scheme calls for a "starter bay" of two adjoining trusses with the permanent lateral bracing connecting them. Two temporary erection posts (towers) are used to provide vertical support, and temporary diagonal bracing is required from each truss bottom chord to a braced level far below in the arena. The contractor will be required to submit his own fully engineered erection scheme. To help assure problem-free truss field assembly, the specifications call for pre-assembling each truss at the fabrication plant to confirm that truss geometry and camber are correct and that field splices will fit accurately.

REFERENCES

Irwin, P.A. and Gamble, S.L., 1992, "Snow Load Predictions for Large Span Roofs", Proceedings International Congress on Innovative Long Span Structures IASS/CSCE, Toronto, Canada.

Johnston, B.G., Ed. Guide to Design Criteria for Metal Compression Members, 3rd ed., 1976, Structural Stability Research Council, John Wiley and Sons, New York, New York.

Kochanski, W.W. and Irwin, P.A., Nov. 16, 1990, "Wind Pressure Tests New Boston Garden, Boston, Massachusetts", Rowan Williams Davies & Irwin, Guelph, Ontario, Canada

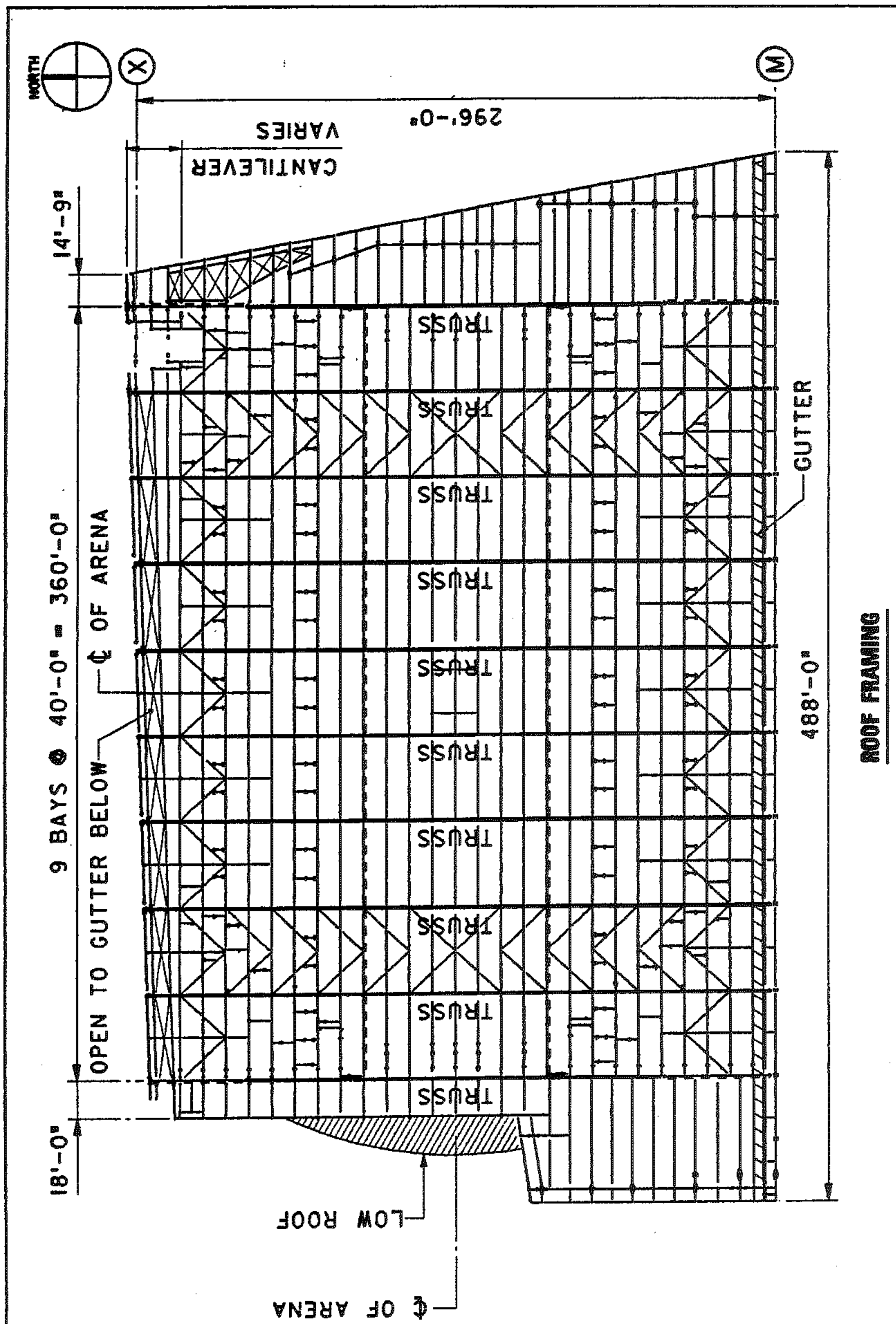

NORTH
X
M
296'-0"
VARIES
CANTILEVER
14'-9"
9 BAYS @ 40'-0" = 360'-0"
OPEN TO GUTTER BELOW
℄ OF ARENA
TRUSS
GUTTER
488'-0"
ROOF FRAMING
18'-0"
LOW ROOF
℄ OF ARENA

Fig. 1

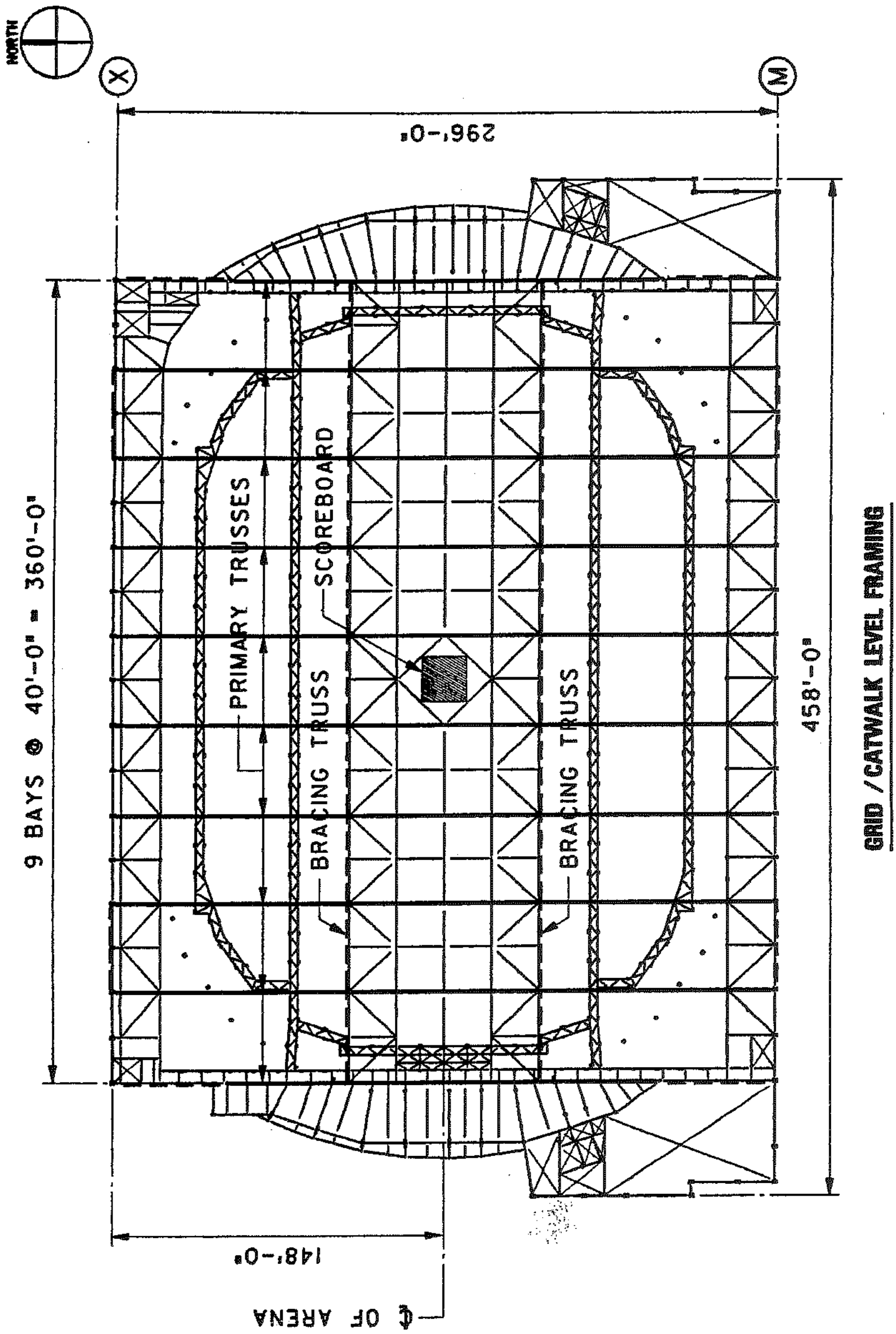

NORTH
X
M
296'-0"
9 BAYS @ 40'-0" = 360'-0"
PRIMARY TRUSSES
SCOREBOARD
BRACING TRUSS
BRACING TRUSS
458'-0"
148'-0"
℄ OF ARENA
GRID / CATWALK LEVEL FRAMING

Fig. 2

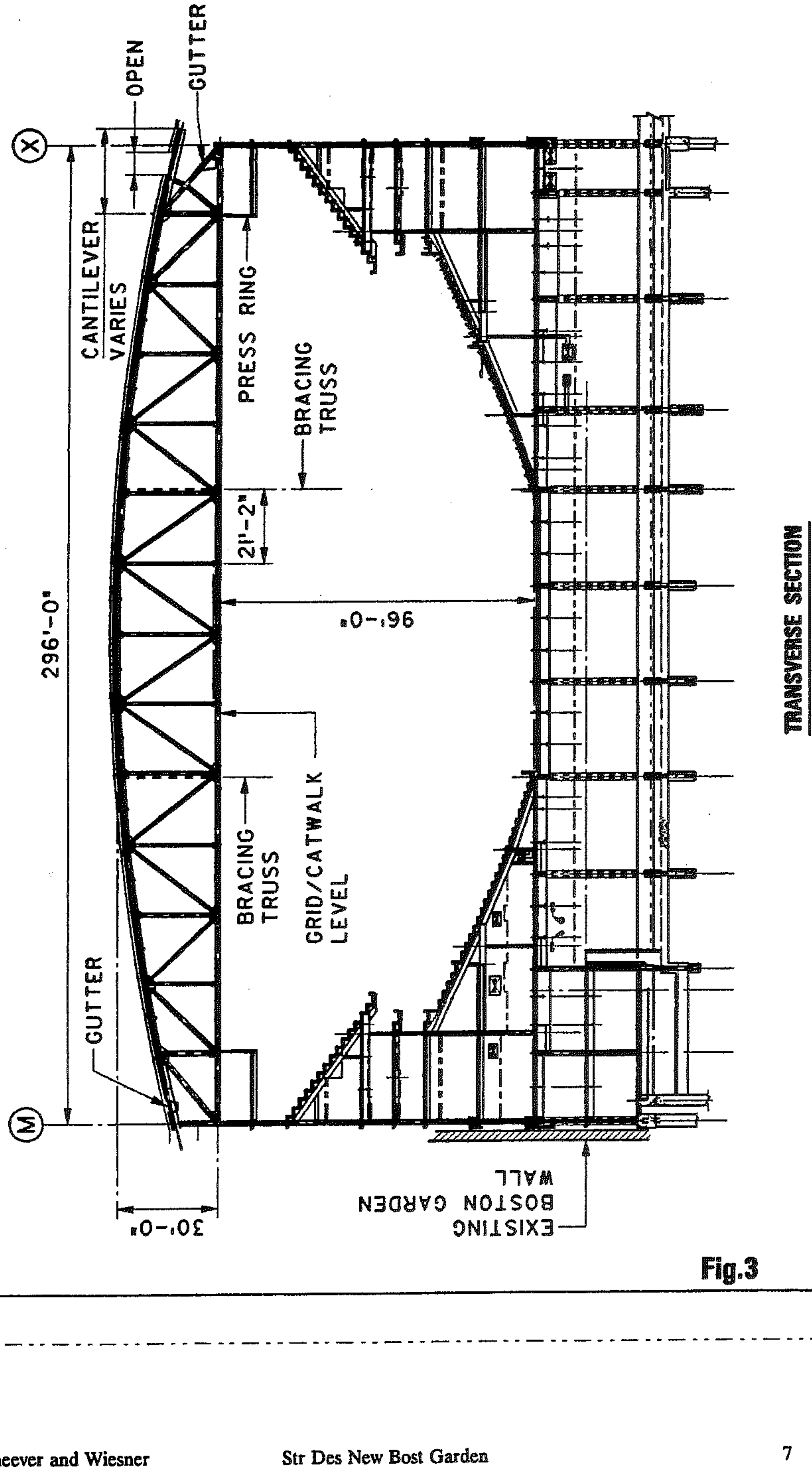
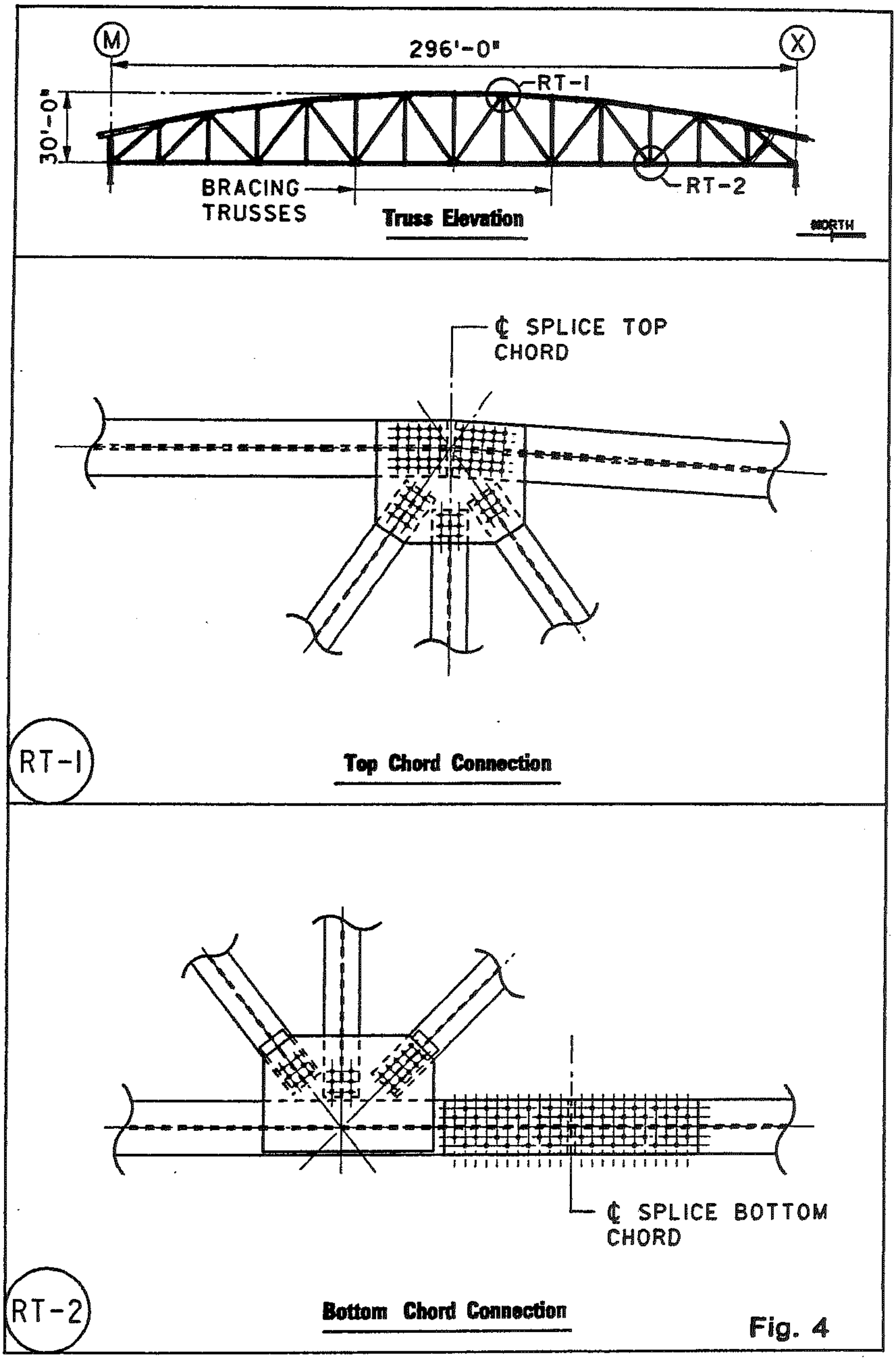

X
OPEN
GUTTER
CANTILEVER
VARIES
PRESS RING
BRACING
TRUSS
21'-2"
296'-0"
96'-0"
BRACING
TRUSS
GRID/CATWALK
LEVEL
GUTTER
M
30'-0"
EXISTING
BOSTON GARDEN
WALL
TRANSVERSE SECTION

Fig.3



M
X
296'-0"
30'-0"
RT-1
RT-2
BRACING
TRUSSES
Truss Elevation
NORTH
₵ SPLICE TOP
CHORD
RT-1
Top Chord Connection
₵ SPLICE BOTTOM
CHORD
RT-2
Bottom Chord Connection

Fig. 4

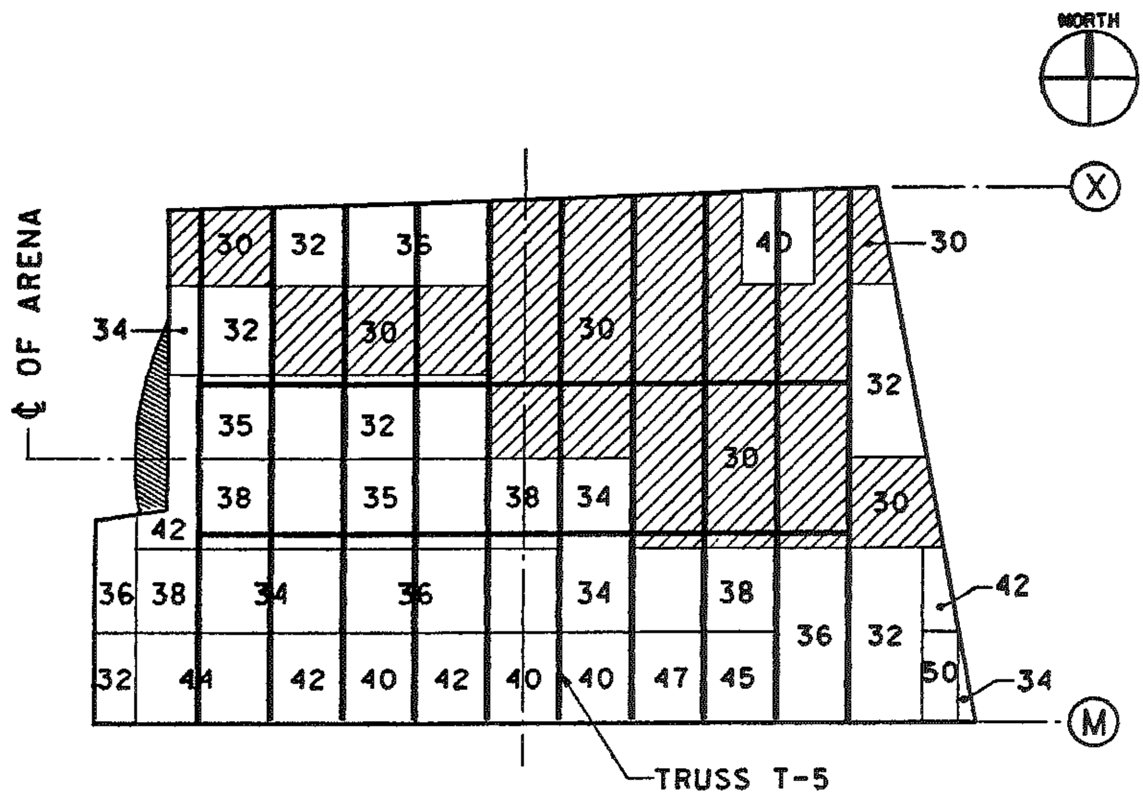


Fig. 5a **Snow Design Load – Roof Purlins PSF**

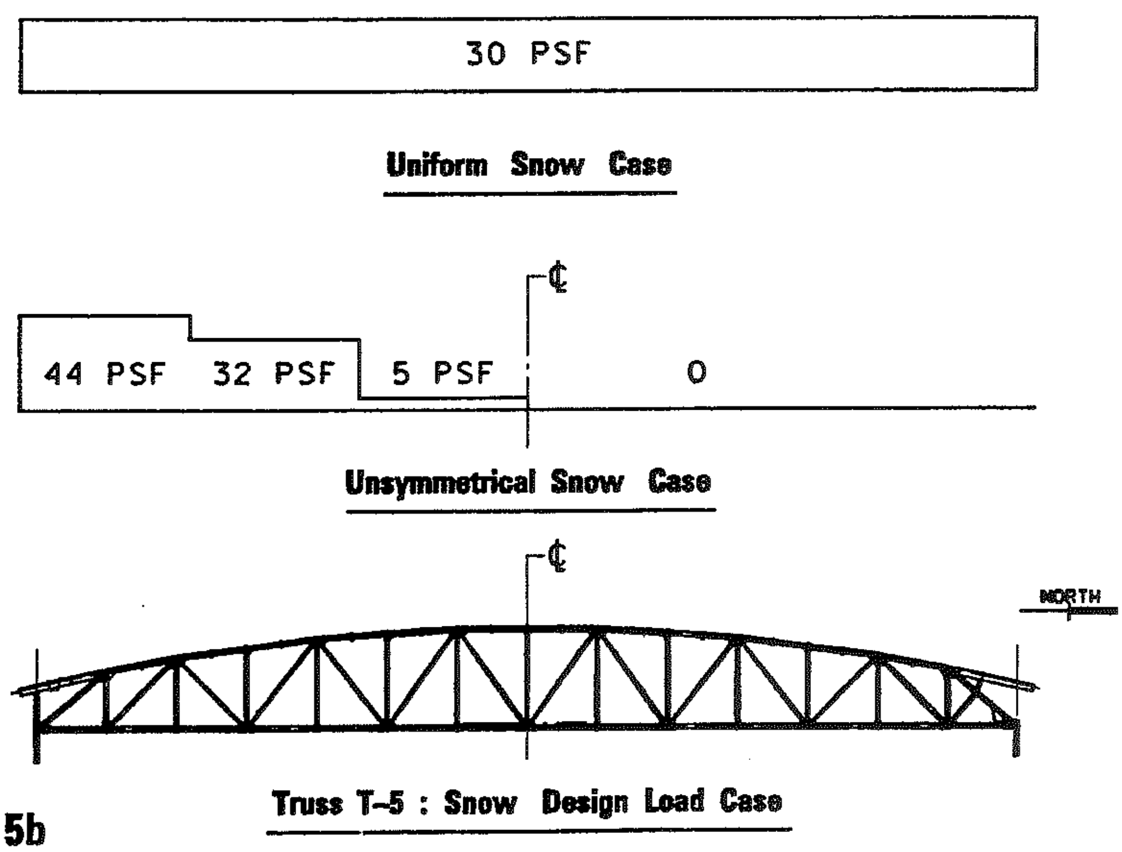


Fig. 5b **Truss T-5 : Snow Design Load Case**

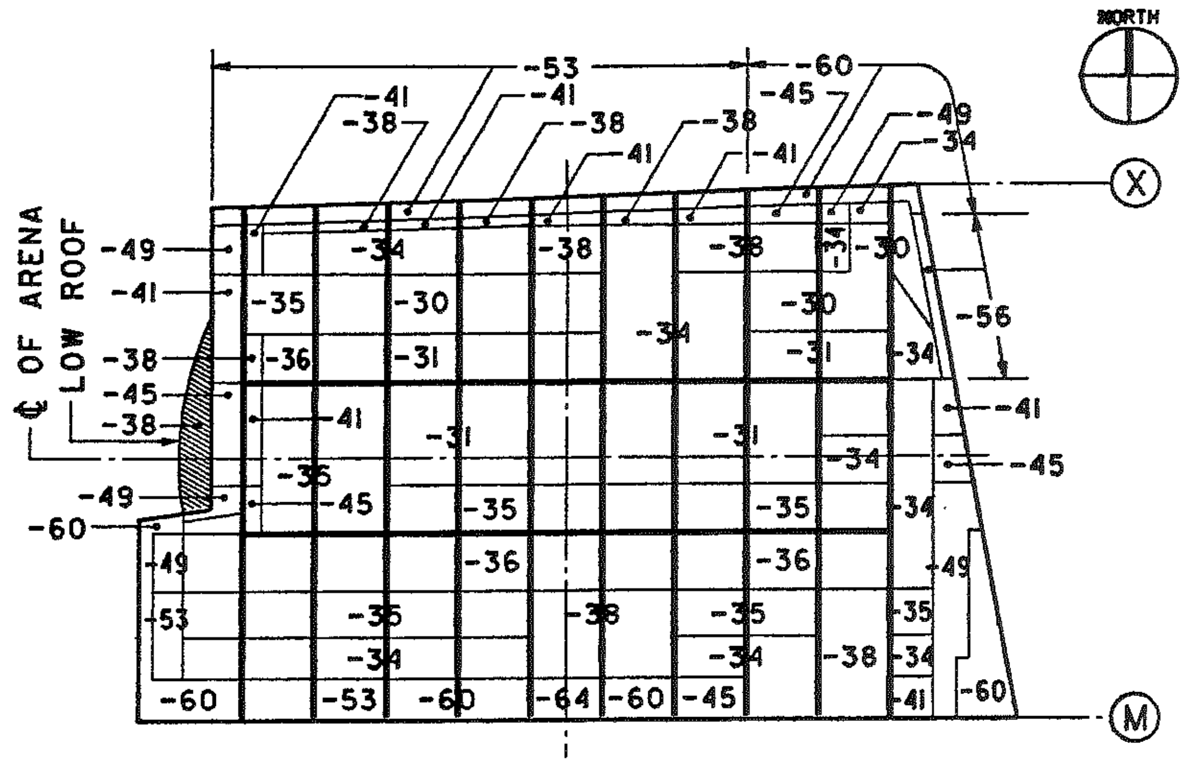


Fig. 6a **Roof Purlins – Negative Wind (Uplift) PSF**

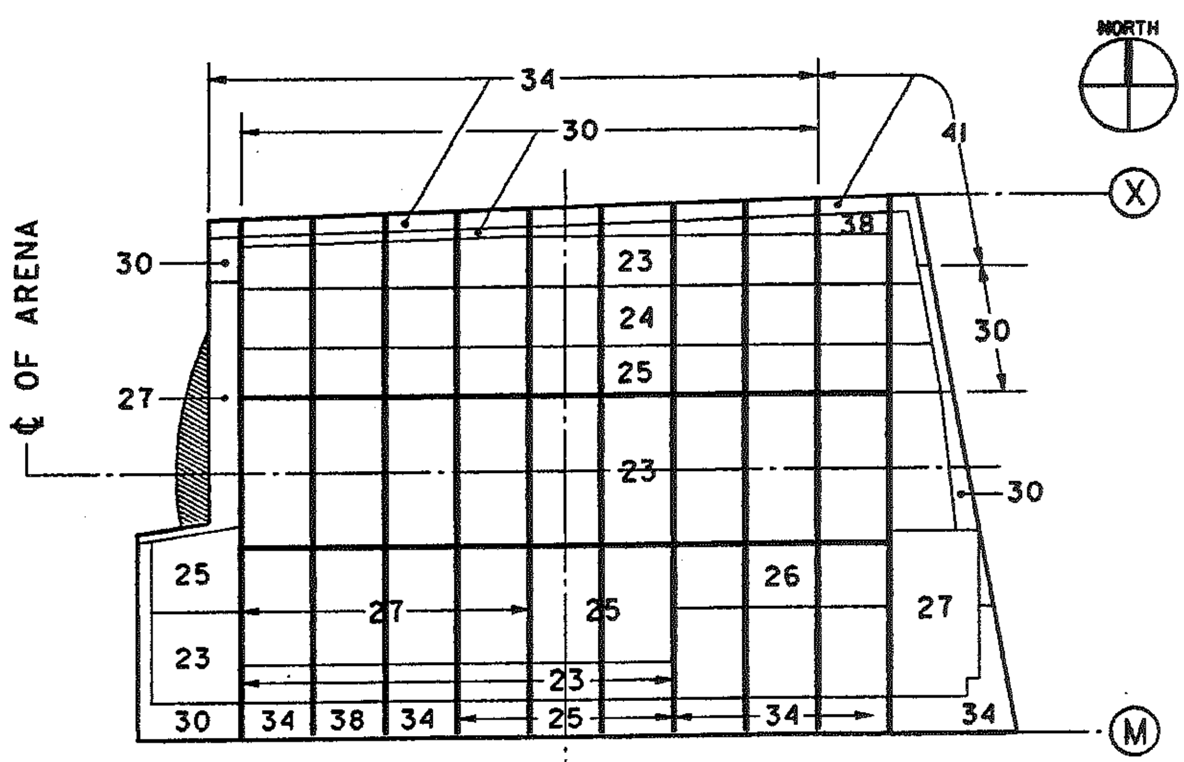
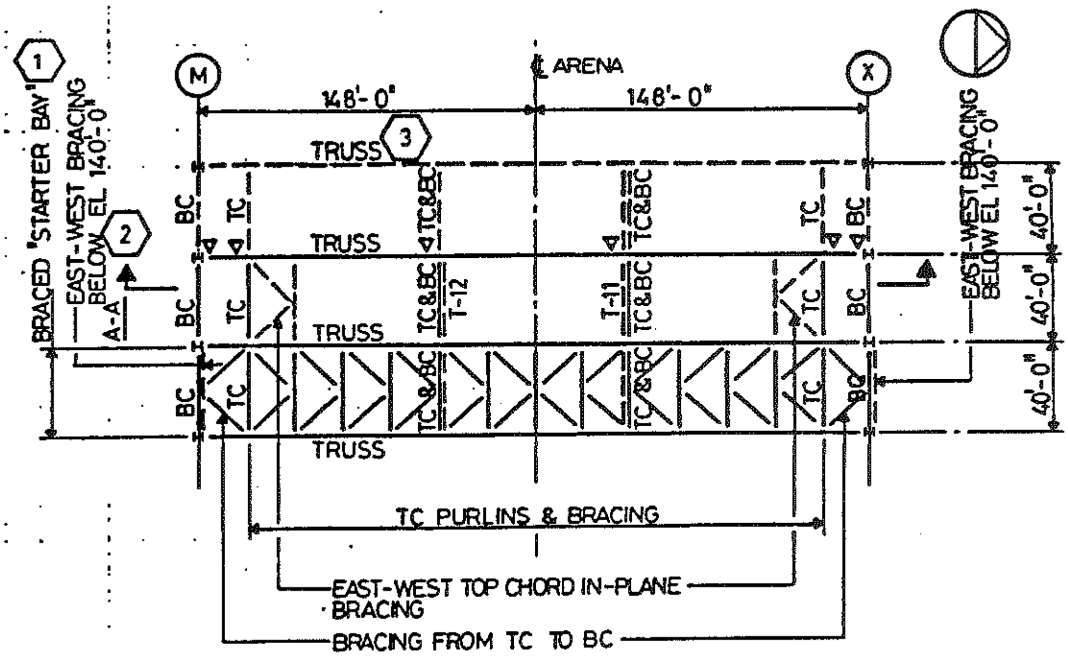


Fig. 6b **Roof Purlins – Positive Wind (Pressure) PSF**

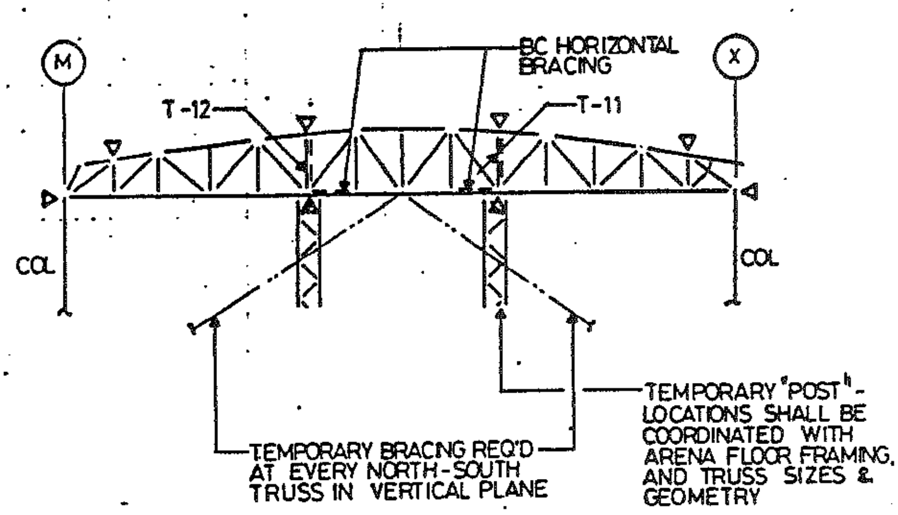


SCHEMATIC PART PLAN

1"=60'-0"

LEGEND

TC	TOP CHORD
BC	BOTTOM CHORD NOTE: BOTTOM CHORD HORIZONTAL BRACING NOT SHOWN
(n)	REFER TO "SUGGESTED ROOF TRUSSES ERECTION SCHEME" PARAGRAPH "n"
▽	POINT ON TRUSS REQUIRING E-W BRACING BACK TO BRACED "STARTER BAY"



ELEVATION A-A

1"= 60'-0"

SUGGESTED ERECTION SCHEME FOR ROOF TRUSSES **Fig. 7**