Version 2014

Verification Manual

August 2014

Table of Contents

1 Introduction

This manual contains a series of sample structural models solved by the *STRAP* analysis program. The examples were selected to provide a representation of a wide range of model types and analysis options. The aim of the manual is to demonstrate the capability of *STRAP* and compare key results with those obtained from theoretical analysis or other computer programs.

Each example contains:

- a short description of the model
- the geometry and loading information required for modeling the structure
- the reference for the theoretical results
- a comparison of the *STRAP* and theoretical results.

Disclaimer

The *STRAP* programs have been written by a team of highly qualified engineers and programmers and have been extensively tested. Nevertheless, the authors of the software do not assume responsibility for the validity of the results obtained from the programs or for the accuracy of this documentation.

The user must verify his own results

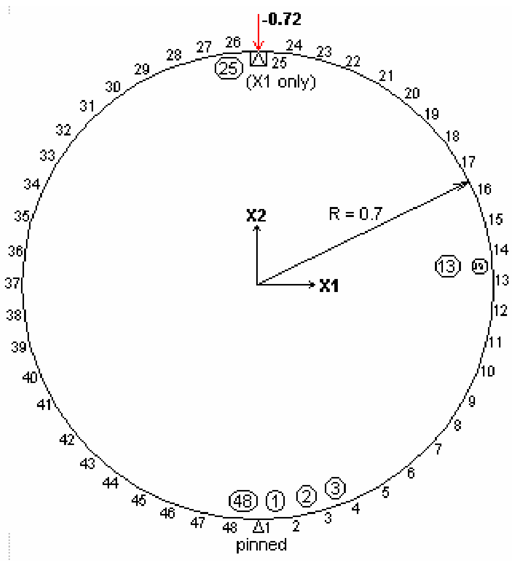
The authors remind the user that the programs are to be used as a tool for structural analysis and design, and that the engineering judgment of the user is the final arbiter in the development of a suitable model and the interpretation of the results.

2 Beam Elements

2.1 Plane frame

Description:

A round concrete pipe simply supported along its bottom edge only, is subjected to a vertical knife edge load along the top edge line.



Geometry:

Inner diameter: 0.6
Outer diameter: 0.8
Thickness: 0.2
Poisson ratio: 0.3
E = 3x106

48 beam elements
Supports: pinned

Loads:

Point load:
FX2 = -0.72 at node 25

Reference:

Roark's Formulas for Stress and Strain
Warren C. Young
McGraw-Hill Book Company
Fourth Edition. Table VIII - Case 1

Calculation:

$+M_{max}$ = 0.3183 WR at x = 0

$-M_{max}$ = -0.1817 WR at x = $\pi/2$

$D_y = -0.149 k_y (WR^3/EI)$

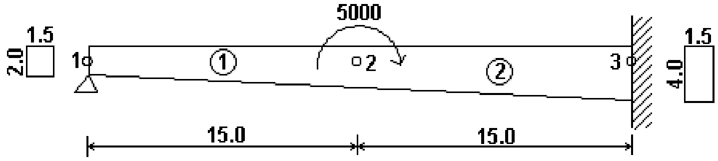
where k_y = 1.03833 for R_o/R_i = 1.3333

Comparison of Results:

Node/beam	Result type	Result		Deviation
		Theoretical	STRAP	
Node 25	Deflection - X2	0.000191	0.000190	0.52%
Beam 25	$+M_{max}$	0.08021	0.08010	0.12%
Beam 13	$-M_{max}$	-0.04579	-0.04590	0.24%

2.2 Tapered beam

A linearly tapered beam, simply supported at one end and fixed at the other end, is subjected to a concentrated moment at mid-span.



Geometry:

Span: 30.0
Beam width: 1.5
Beam depth (right): 2.0
Beam depth (left): 4.0

Elements: 2 tapered

Supports: Pinned at left
Fixed at right

Loads:

Concentrated moment: -5000 at midpoint

Reference:

Roark's Formulas for Stress and Strain
Warren C. Young
McGraw-Hill Book Company
Fourth Edition.

Table 3 - Case 3c
Table 13c

Calculation:

The tables in the reference are accurate only to three significant figures; the STRAP results have been rounded off accordingly.

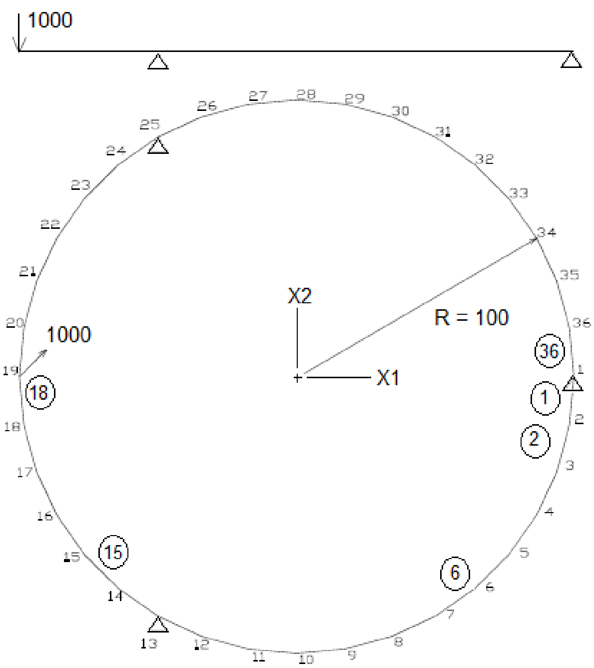
Comparison of Results:

Node/beam	Result type	Result		Deviation
		Theoretical	STRAP	
Node 1,3	Reaction	169.9	169.8	-
Node 2	Moment to left	-2549	-2548	-
Node 2	Moment to right	2451	2452	-

2.3 Pipe - grid

Description:

A grid in the form of a circular ring beam rests on three equally spaced simple supports. A concentrated load is applied midway between two of the supports.



Geometry:

Radius: 100 in.

Elements: 36 identical beams
Property: Round bar, diam = 2.7 in.
Material: E = 107 lb/in^2; = 0.3
Supports: 3 equally spaced pinned supports (X3)

Loads:

Concentrated load: 1000 lb (X3)

Reference:

Roark's Formulas for Stress and Strain
Warren C. Young
McGraw-Hill Book Company
Sixth Edition.

Table 19; Article 8.5, Example 3

Calculation:

The *STRAP* model consists of 36 straight beam segments, i.e. the model is not continuously circular. This leads
to the slight discrepancy in the results.

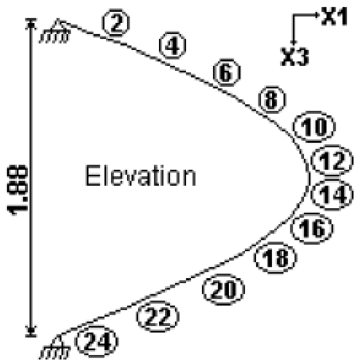
Comparison of Results:

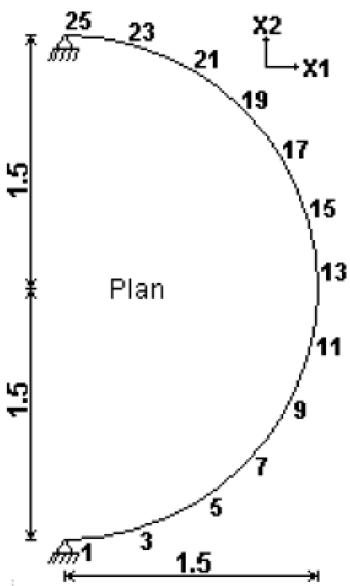
Beam	Result type	Result		Deviation
		Theoretical	STRAP	
18	M2 moment	38490	38344	0.38%
1	M2 moment	19250	19172	0.41%
6	MT moment	-8790	-8721	0.78%
15	MT moment	13100	13225	0.95%

2.4 Spiral stair

Description:

A helical stair is modeled as a three dimensional frame consisting of beam elements.





Geometry:

Radius to centre line of stairs: 1.5

Total vertical rise: 1.885

Stair dimensions: 1.5 width x 0.15 depth

Modulus of Elasticity: 3,000,000
Poisson ratio: 0.3

Elements: 24 beam elements

Supports: Pinned

Loads:

Distributed projected load X3 = -1.0

Comparison of Results:

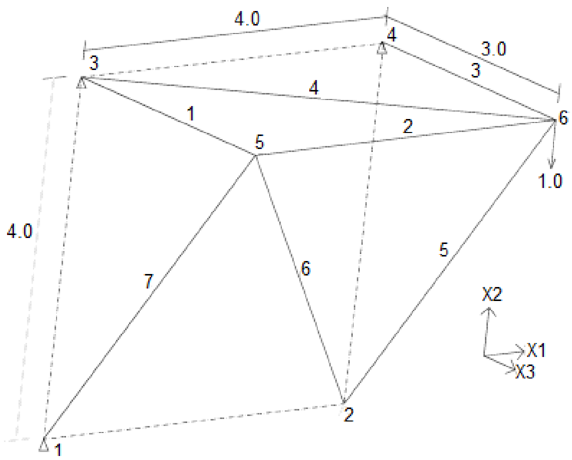
The *STRAP* results were compared to those obtained using the SAP80 analysis program.

Beam	Result type	Result		Deviation
		SAP80	STRAP	
24	M3 moment	-3.358	-3.358	-
1	Axial force	2.796	2.796	-

2.5 Space truss

Description:

A statically indeterminate cantilever space truss as shown below, loaded with a joint load and a uniform temperature load.



Geometry:

Modulus of Elasticity: 30,000 ksi
Thermal coefficient: 11.7x10-6 (in/in)/°C
Area: 1.0 in^2
Elements: beam elements
Supports: Pinned

Loads:

Joint load FX2 = -1.0

Axial temperature change = +27.8°C (all beams)

Reference:

Theory of Structures
Timoshenko and Young
McGraw-Hill Book Company
Second Edition.

Article 7.6 - Problems 1,2

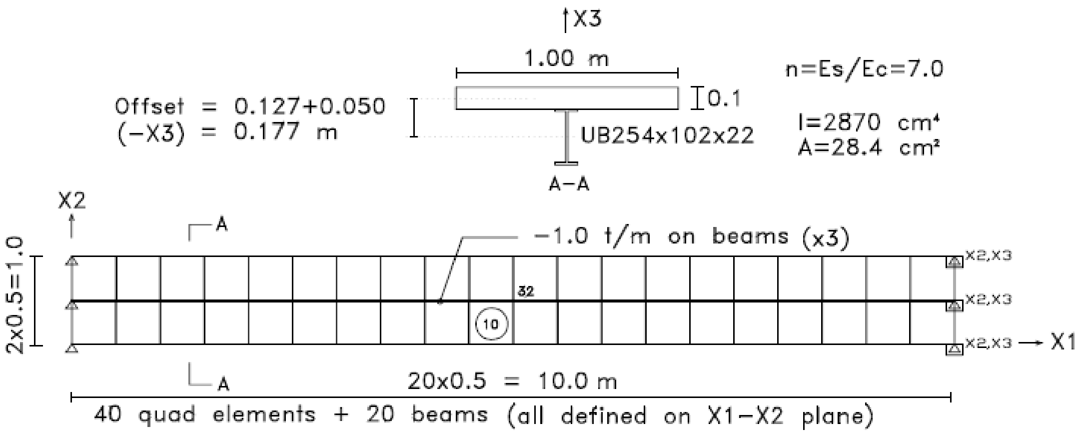
Comparison of Results:

Beam	Load	Result type	Result		Deviation
			Theoretical	STRAP	
4	Joint	Axial	0.056	0.056	-
4	Temperature	Axial	1.295	1.294	0.07%

2.6 Composite beam - offsets

Description:

A simply supported composite beam - steel section and concrete slab - loaded with a uniformly distributed load.
All beams and elements in this space model are defined on the X1-X2 global plane; beam offsets are used to place the steel section below the slab, thereby generating the increased moment-of-inertia of the composite section. Note that the structure must be defined as a space model in order to specify X3 offsets.



Geometry:

Modulus of Elasticity: Concrete: 300,000 t/m2 Steel: 2,100,000 t/m2

Loads:

Beam load: FX3 = -1.0 t/m on all beams (total load = 10 t)

Reference:

Roark's Formulas for Stress and Strain - 6th edition
Warren C. Young
McGraw-Hill Book Company

Table 3 - Case 2c (deflections)

Comparison of Results:

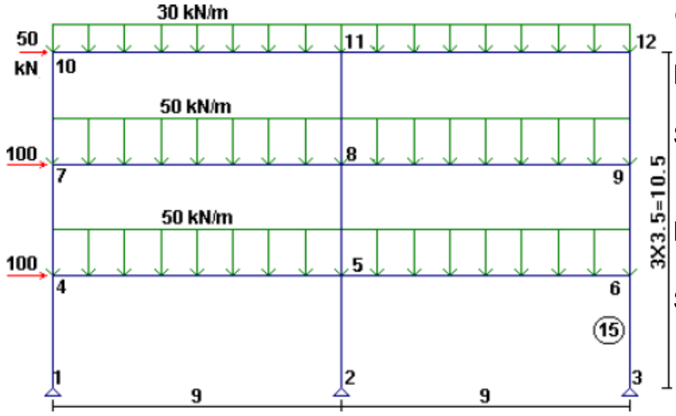
Location	Result type	Result			Deviation
		Theoretical	STRAP	STRAP (no offset)	
Node 32	Deflection	0.054 m	0.0548	(0.153)	1.5%
Element 10	Neutral axis	79.3 mm	79.0*	-	0.38%

* The neutral axis location is calculated from the interpolation of +SX and -SX values.

2.7 P-Delta

Description:

A three storey plane frame is analyzed for the additional bending moments and forces generated by the vertical loads acting through the deflected shape of the frame.



Geometry:

Dimensions: as shown above

Sections: UB 533x210x122 (British steel I-beam)

Material: Steel - E_s = 204,100 kN/mm^2

Supports: pinned

Loads:

as shown above

Reference:

Limit States Design in Structural Steel
G.L. Kulak, P.F. Adams, M.I Gilmor
Canadian Institute of Steel Construction
4th Edition 1990
Chapter 9.4

Calculation:

$$M_f = M_{fg} + U_2 M_{ft}$$

where:

M_f = total factored moment at the beam end including 2nd order effects
M_{fg} = first order moment due to factored gravity load
M_{ft} = first order moment due to factored lateral load
U_2 = $1/(\Sigma C_f \Delta_f / \Sigma V_f h)$
V_f = Total first order lateral shear
C_f = Total vertical axial load
h = storey height
Δ_f = relative lateral deflection within the storey height, produced by the first order lateral shear only.

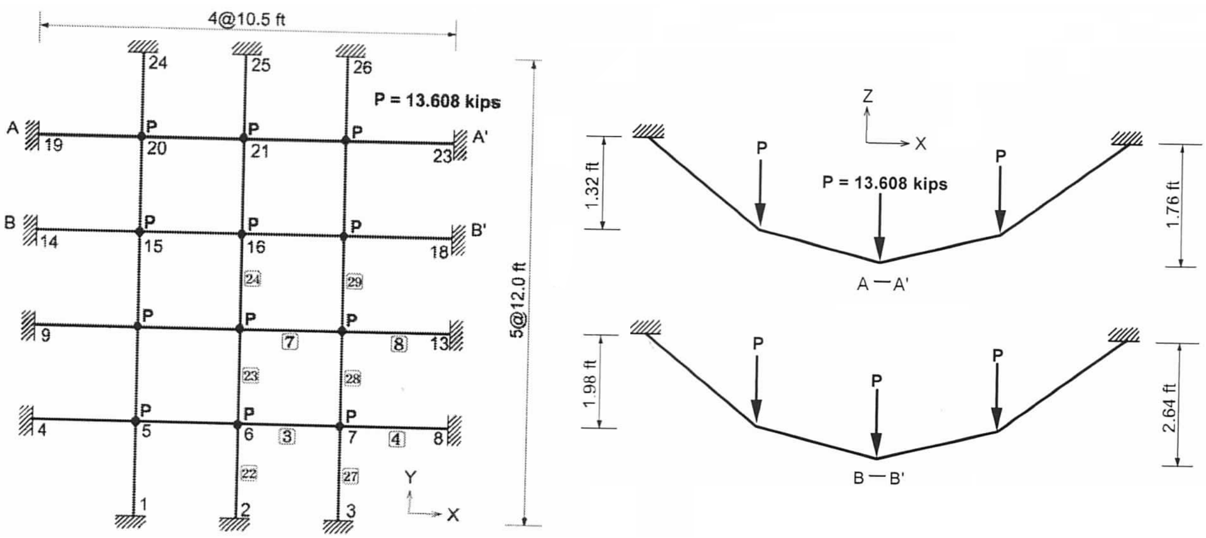
Comparison of Results:

Beam	Result type	Result		Deviation
		Theoretical	STRAP	
15	M_f	388 kN	389	0.26%

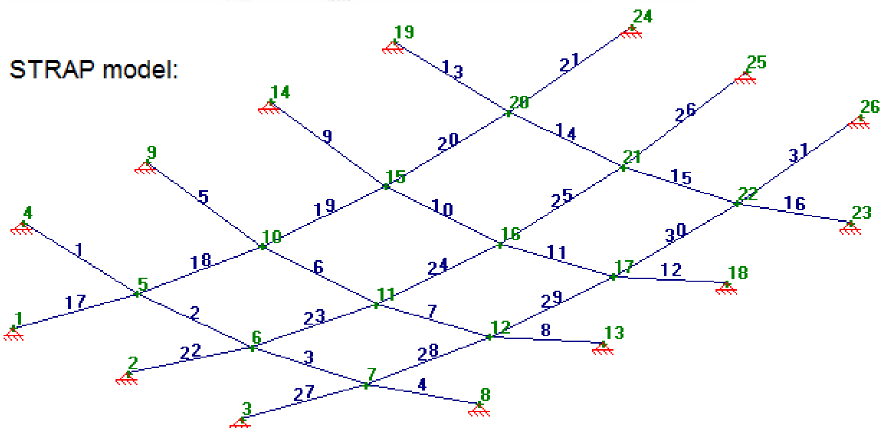
2.8 Cable element

Description:

A cable net structure is subject to vertical loads applied at its interior nodes:



STRAP model:



Geometry:

Modulus of elasticity: $3.6x10^6$ ksf
Poisson's ratio : 0.0
Cable area: 0.01 ft^2
Supports: exterior nodes: all DOFs fixed

Loads: see the drawing above

Reference:

"Midas" Verification Manual.

The manual presents results from three references:

1. John W. Leonard, "Tension Structures", pp115-7
   McGraw Hill, 1988
2. A. Lo, "Nonlinear dynamic analysis of cable and membrane structures"
   Ph.D. Dissertation, Oregon State University, 1981

3. Baron & Vendatesan, "Nonlinear Analysis of cable and truss structures", Journal of the structural Division, ASCE, Vol 97, pp. 679-710, 1971.

Comparison of results:

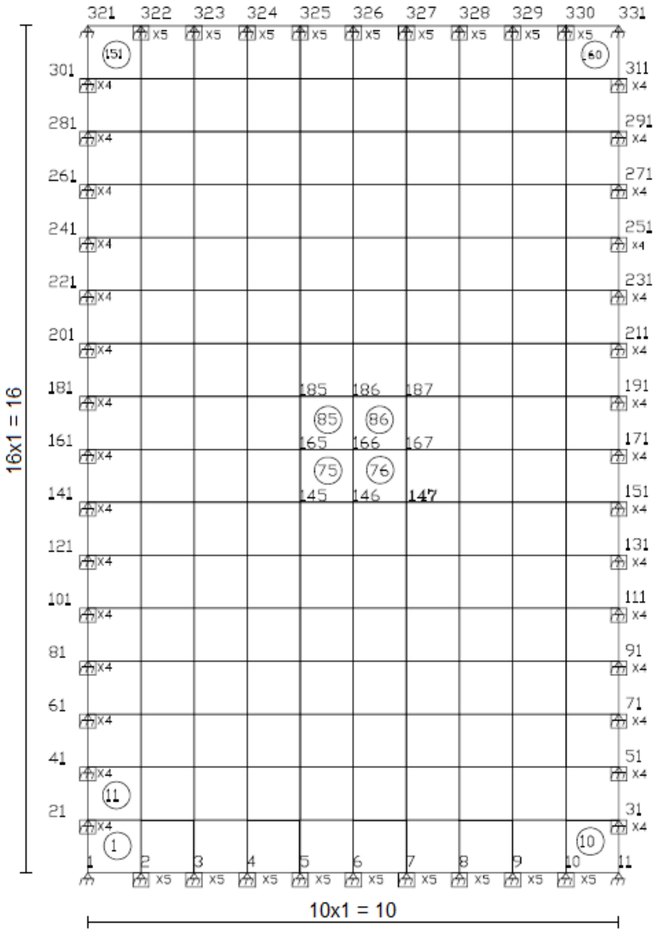
Beam/Node	Result type	Result				Deviation
		Theoretical			STRAP	
		Ref.1	Ref.2	Ref.3		
Node 21	Deflection - Z	-0.351	-0.351	-0.352	**-0.352**	-
Node 21	Deflection - Y	0.0366	0.0366	0.0367	**0.0367**	-
Beam 8	Axial	80.0	80.0	80.0	**80.1**	0.13%
Beam 24	Axial	57.9	57.9	57.8	**57.9**	-

3 Finite Elements

3.1 Plate bending

Description:

A thin rectangular plate, simply supported along all four edges, subject to a uniformly distributed area load.



Geometry:

Dimensions: 10 x 16
Thickness: 0.2
Modulus of Elasticity: 1,000,000
Poisson ratio: 0.3

Elements: 10 x 16 grid rectangular elements

Supports: Pinned (restrained against rotation parallel to edge).

Loads:

Uniform pressure: -1.0 on all elements

Reference:

Theory of Plates and Shells - 2nd Edition
Timoshenko and Woinowsky-Kreiger
McGraw-Hill Book Company
Chapter 5 - Table 6

Comparison of Results:

Element	Node	Result type	Result		Deviation
			Theoretical	STRAP	
-	166	Deflection	0.11341	0.11317	0.21%
86	166	M_x	8.62	8.652	0.37%
86	166	M_y	4.92	4.936	0.32%

3.2 Concrete design moments

Description:

The plate bending model of example 3.10 is used to verify the calculation of the concrete design moments (Wood & Armer).

The Wood & Armer equations are listed in the STRAP User's Manual. Note that these equations are based on the standard engineering sign convention (sagging moment = positive), while the STRAP sign convention gives opposite results (sagging moment = negative). For clarity, the calculations in this example use the standard engineering sign convention.

Geometry / Loads:

Refer to the previous Plate bending example.

Reference:

"The Reinforcement of Slabs in Accordance with a Pre-determined Field of Moments"
R.H. Wood
"Concrete" magazine - February 1968

STRAP Results:

Element	Element results			Wood & Armer moments			
				Bottom		Top	
	M_x	M_y	M_{xy}	Mx*	My*	Mx*	My*
1	0.2802	0.2392	4.166	4.446	4.405	-3.885	-3.926
32	3.357	2.163	2.354	5.711	4.517	0.0	0.0
51	1.601	0.8648	1.422	3.023	2.286	0.0	-0.3975
75	8.459	4.840	0.0438	8.503	4.884	0.0	0.0

Calculation of Results:

The Wood & Armer moments were verified by hand calculation and are summarized in the following table. The results are identical.

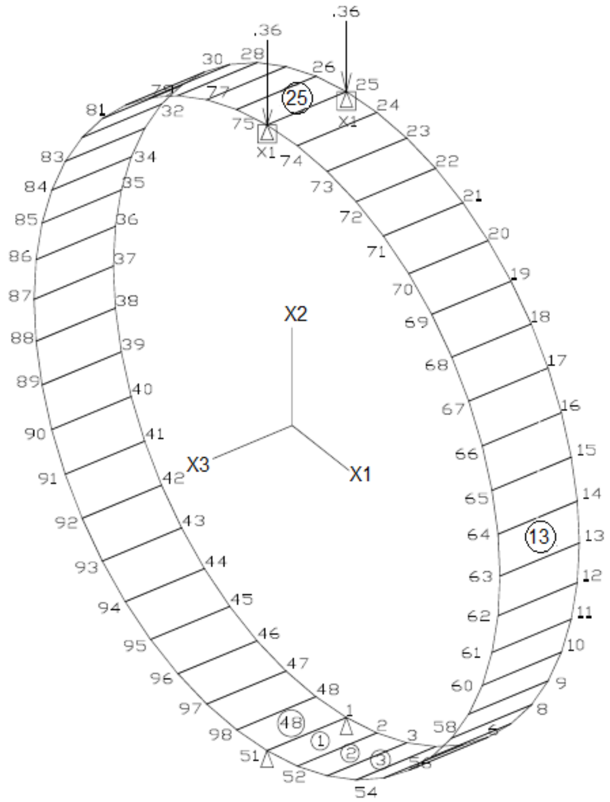
	Bottom	Top
Equations	$M_x^* = M_x + \lvert M_{xy} \rvert$ $M_y^* = M_y + \lvert M_{xy} \rvert$ $If\ \ M_x^* < 0 :\ \ M_x^* = 0$ $M_y^* = M_y + \left\lvert \frac{M_{xy}^2}{M_x} \right\rvert$ $If\ M_y^* < 0 :\ \ M_y^* = 0$ $M_x^* = M_x + \left\lvert \frac{M_{xy}^2}{M_y} \right\rvert$	$M_x^* = M_x - \lvert M_{xy} \rvert$ $M_y^* = M_y - \lvert M_{xy} \rvert$ $If\ \ M_x^* > 0 :\ \ M_x^* = 0$ $M_y^* = M_y - \left\lvert \frac{M_{xy}^2}{M_x} \right\rvert$ $If\ M_y^* > 0 :\ \ M_y^* = 0$ $M_x^* = M_x - \left\lvert \frac{M_{xy}^2}{M_y} \right\rvert$

Element	Mx*	My*	Mx*	My*
1	0.2802 + 4.166 = 4.4462	0.2392 + 4.166 = 4.4052	0.2802 - 4.1666 = -3.8858	0.2392 - 4.166 = -3.9268
32	3.357 + 2.534 = 5.711	2.163 + 2.354 = 4.517	3.357 - 2.354 = 1.003 but $M_x^* > 0$: use $M_x^* = 0$ and $M_y^* = 2.163 - \left\lvert \frac{2.354^2}{3.357} \right\rvert$ = 0.5123 but $M_y^* > 0$: use $M_y^* = 0$	2.163 - 2.354 = 0.191
51	1.601 + 1.422 = 3.023	0.8648 + 1.422 = 2.2868	1.601 - 1.422 = 0.179 but $M_x^* > 0$: use $M_x^* = 0$ and $M_y^* = 0.8648 - \left\lvert \frac{1.422^2}{1.601} \right\rvert$ = -0.3980	0.8648 - 1.422 = -0.5572
75	8.459 + 0.0438 = 8.5028	4.840 + 0.0438 = 4.8838	8.459 - 0.0438 = 8.4152 but $M_x^*, M_y^* > 0$: use $M_x^*, M_y^* = 0$	4.840 - 0.04438 =4.762

3.3 Pipe - elements

Description:

A round concrete pipe simply supported along its bottom edge only, is subjected to a vertical knife edge load along the top edge line (identical to the Pipe - grid example).



Geometry:

Inner diameter: 0.6
Outer diameter: 0.8
Thickness: 0.2
Poisson ratio: 0.3
Modulus of Elasticity: 3,000,000

Elements: 48 rectangular elements

Supports: Pinned

Loads:

Concentrated load:
-3.6 at nodes 25 and 75

Reference:

Roark's Formulas for Stress and Strain
Warren C. Young
McGraw-Hill Book Company
Fourth Edition. Table VIII - Case 1

Calculation:

$+M_{max}$ = 0.3183 WR at x = 0

$-M_{max}$ = -0.1817 WR at x = $\pi/2$

$D_y = -0.149 k_y (WR^3/EI)$

where k_y = 1.03833 for R_o/R_i = 1.3333

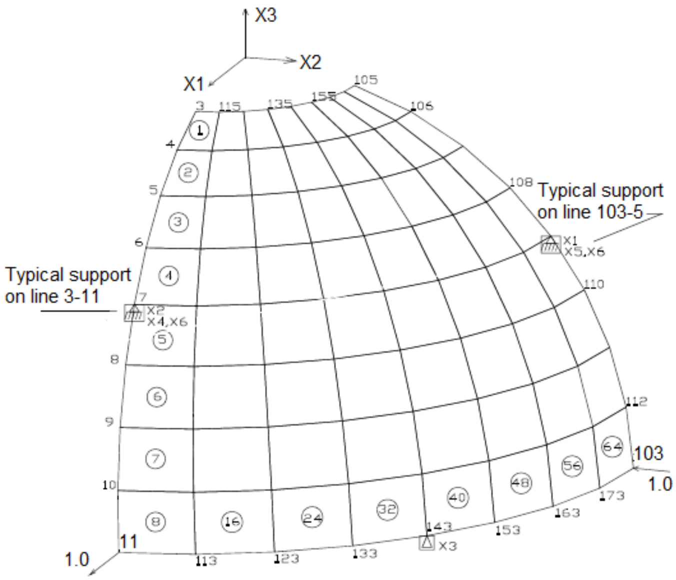
Comparison of Results:

Element	Node	Result type	Result		Deviation
			Theoretical	STRAP	
-	25	Deflection - y	0.000191	0.000190	0.52%
25	25	$+M_{max}$	0.08021	0.08130	1.34%
13	13	$-M_{max}$	-0.04579	-0.04598	0.41%

3.4 Space shell

Description:

A hemispherical shell with an opening at its top is loaded with point loads along its edge. As the geometry and loading is symmetrical, only one-quarter of the shell is modeled.



Geometry:

Modulus of Elasticity: 6.825x107
Radius: 10.0
Thickness: 0.4
Poisson ratio: 0.3

Elements: rectangular

Supports:

- Symmetry supports along the side of the shell;
- a support for stability at the midpoint of the base.

Loads:

- Concentrated load: 1.0 at node 11
- -1.0 at node 103

Reference:

"A Proposed Set of Problems to Test Finite Element Accuracy"
MacNeal, R.H. and Harder, R.C.
Finite Elements in Analysis and Design
North Holland, 1985.

Calculation:

The reference gives 0.094 as the value for comparison of results.

Comparison of Results:

Node	Result type	Result		Deviation
		Theoretical	STRAP	
11, 103	Deflection in the direction of load	0.094	0.0902	4.04%

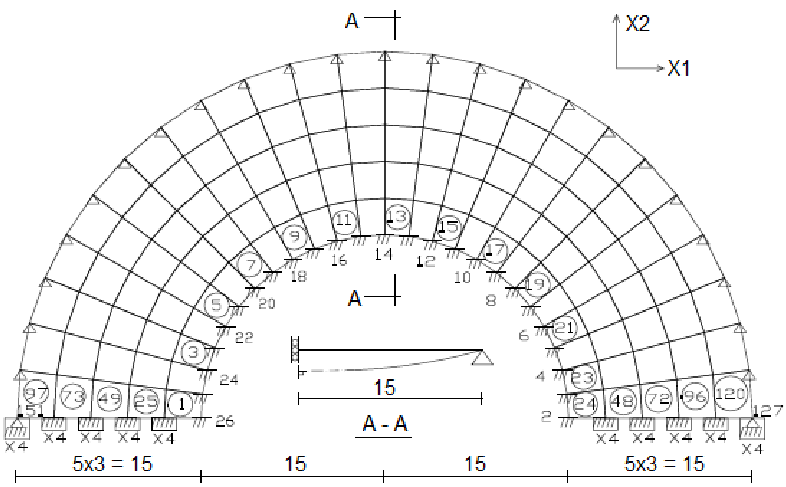
3.5 Guided ring

Description:

A slotted ring, simply-supported on its outer edge and guided (vertical motion only, no rotation) on its inner edge,
is loaded with a uniformly distributed load.

As the geometry and loading is symmetrical, only one-half of the ring is modeled.

The model is solved with both quadrilateral and triangular finite elements (plate elements).



Geometry:

Radius:

- internal: 15.0
- external: 30.0

Thickness: 0.5
Modulus of Elasticity: $3.0x10^7$
Poisson ratio: 0.3

Elements:

- rectangular
- triangular

Supports:

- outer edge: pinned
- inner edge:guided

Loads:

Uniform load: -10.0

Reference:

Roark's Formulas for Stress and Strain
Warren C. Young
McGraw-Hill Book Company
Sixth Edition.

Table 24 - Case 2b

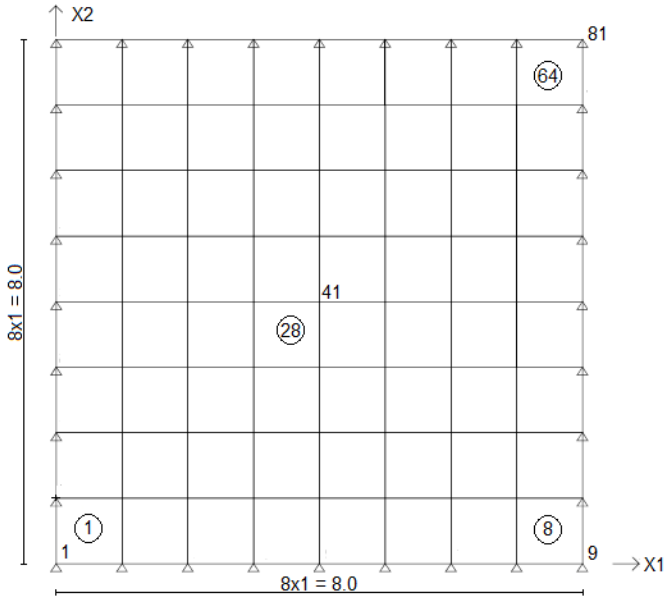
Comparison of Results:

Element type	Element	Node	Result type	Result		Deviation
				Theoretical	STRAP	
Quad.		82	Deflection	0.243	0.245	0.82%
	24	2	Moment	1100.7	1104.6	0.35%
Tri.		82	Deflection	0.243	0.243	0.00%
	24	2	Moment	1100.7	1091.1	0.80%

3.6 Orthotropic plate

Description:

A square orthotropic plate is loaded with a uniformly distributed load.



Geometry:

Dimensions: 8.0 x 8.0
Thickness: 0.5

Modulus of Elasticity:
- E_x: 11.9 x10^6
- E_y: 0.60x10^6

Poisson ratio:
- Case I: 0.3
- Case II: 0.0

Elements: rectangular

Support: Pinned

Loads:

Uniform load: -10.0

Reference:

Plate Analysis
Weinberg, D.V. and Weinberg,
E.D. Budevelnik Press
Kiev, Ukraine, 1970

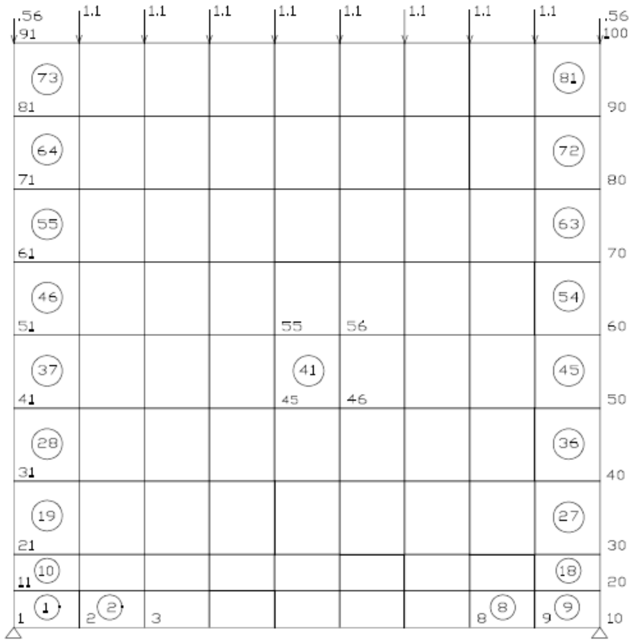
Comparison of Results:

Case	Element	Node	Result type	Result		Deviation
				Theoretical	STRAP	
1	-	41	Deflection	0.00345	0.00345	0.00%
	28	41	Mx	64.30	65.32	1.59%
	28	41	My	3.24	3.24	0.00%
2	-	41	Deflection	0.00347	0.00347	0.00%
	28	41	Mx	63.62	64.64	1.60%
	28	41	My	2.27	2.26	0.44%

3.7 Plane stress

Description:

A concrete wall, simply supported at the two bottom corners, is subjected to a uniform load along its top edge.



Geometry:

Dimensions: 10.0 x 10.0
Thickness: 0.10
Modulus of Elasticity: $3.0*10^6$
Poisson ratio: 0.15

Elements: rectangular

Supports: Pinned

Loads:

Uniform load: -1.0 t/m on the top edge

Reference:

The *STRAP* results were compared to those obtained using the SAP80 analysis program.

Comparison of Results:

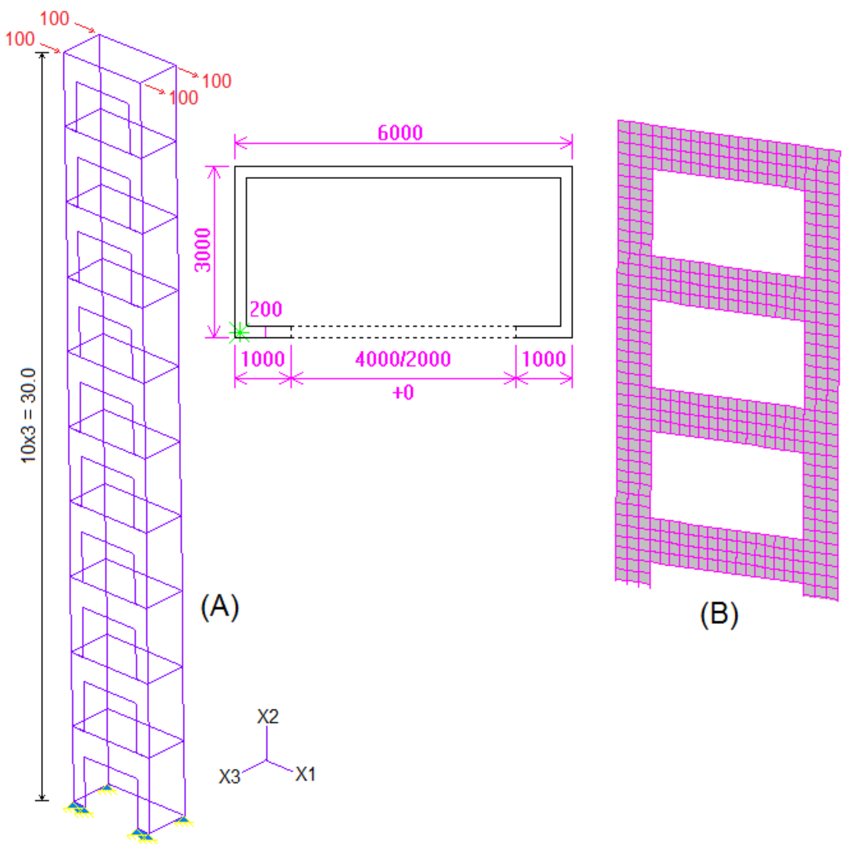
The S_x results were compared at the center point of the bottom edge of the following elements:

Element	Node	STRAP	SAP80	% Difference
1	1	-42.74	-42.66	0.19%
2	2	22.55	22.45	0.45%
6	6	6.72	6.67	0.75%
41	45	-5.992	-5.958	0.57%

3.8 Wall elements

Description:

A concrete core wall with a coupling beam created with the *STRAP* Wall option (Figure A), is subjected to a horizontal load at the top. The results are compared to those from the same model created with a more refined mesh of elements (Figure B).



Geometry:

E = 3.0*106
Poisson ratio = 0.15

Supports: Fixed

Comparison of Results:

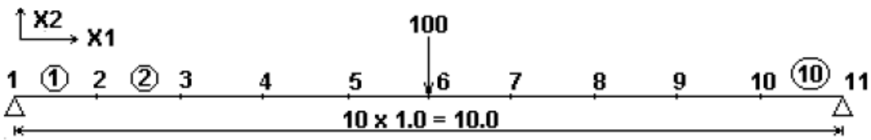
Result type & location	Wall elements	Element mesh	% difference
Moment - X2 = 0.0 - 6 m wall	3561	3457	3.0%
Moment - X2 = 9.0 - 6 m wall	2239	2239	0.0%
Moment - X2 = 18.0 - 6 m wall	1111	1114	0.3%
Shear - X2 = 0.0 - 6 m wall	268	264	1.5%
Shear - X2 = 9.0 - 6 m wall	251	251	0.0%
Shear - X2 = 18.0 - 6 m wall	228	222	2.7%
Moment - X2 = 3.0 - coupling beam	104	104	0.0%
Moment - X2 = 9.0 - coupling beam	153	153	0.0%
Moment - X2 = 18.0 - coupling beam	184	184	0.0%
X1 deflection - top of wall	10.49	10.59	0.9%

4 Dynamic analysis

4.1 Natural frequency - beam

Description:

A simply supported rectangular beam, subject to a concentrated weight at the mid-point.



Geometry:

Span length: 10.0
Section Dimension: 0.5 x 0.5
Modulus of Elasticity: 21,000,000
Poisson ratio: 0.3

Elements: 10 equal beam elements

Supports: Pinned supports at both ends

Loads:

Nodal weights: 100.0 tons at mid-span

Reference:

Roark's Formulas for Stress and Strain
Warren C. Young
McGraw-Hill Book Company
Sixth Edition.
Table 36 - Case 1

Calculation:

$$f = (6.93/2\pi)\sqrt{(EIg/Wl^3)}$$

where:
E = modulus of elasticity
I = moment of inertia
g = gravitational constant = 9.81
W = Concentrated load
l = span length

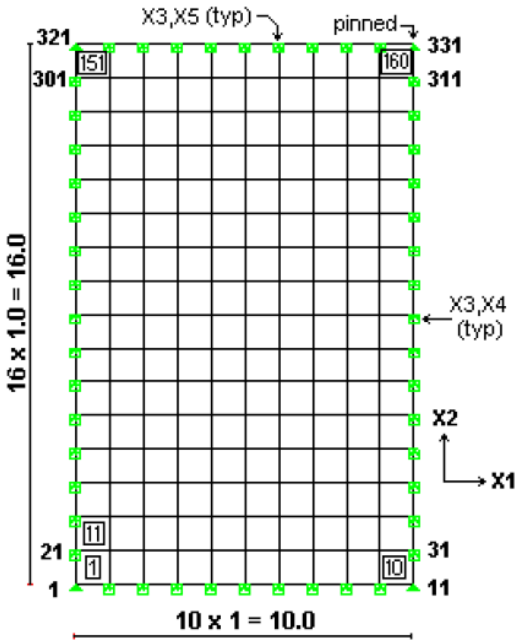
Comparison of Results:

Result type	Result		Deviation
	Theoretical	STRAP	
Natural frequency - Mode 1	3.6123	3.5982	0.39%

4.2 Natural frequency - plate

Description:

A thin rectangular plate, simply supported along all four edges, subject to a uniformly distributed area load.



Geometry:

Dimensions: 10 x 16
Thickness: 0.2
Modulus of elasticity: 1,000,000
Poisson ratio: 0.3

Elements: 10 x 16 grid rectangular elements

Supports:
Pinned (restrained against rotation parallel to edge).

Loads:

Nodal weights:

- 1.00 - internal nodes
- 0.50 - edge nodes
- 0.25 - corner nodes

Reference:

Roark's Formulas for Stress and Strain
Warren C. Young
McGraw-Hill Book Company
Sixth Edition.
Table 36 - Case 15

Calculation:

$$f_n = \frac{K_n}{2\pi}\sqrt{\frac{D_g}{wa^4}} \qquad K_n = \pi^2\left[1+\left(\frac{a}{b}\right)^2\right] \qquad D = \frac{Et^3/12}{1-\nu^2}$$

where:
a = short dimension
b = long dimension
t = plate thickness
g = gravitational constant = 9.81
w = applied weight per unit area
ν = Poisson ratio

Comparison of Results:

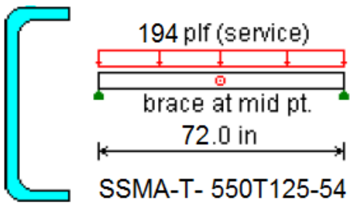
Result type	Result		Deviation
	Theoretical	STRAP	
Natural frequency - Mode 1	1.8515	1.8538	0.12%

5 Steel design

5.1 AISI - cold formed beam

Description:

A simply supported cold-formed beam, braced at mid-point, uniformly loaded:



Geometry:

- Steel: F_y = 33 ksi
- Section: SSMA-T 550T125-54

Loads:

As shown above.

Reference:

AISI Manual - Cold-formed Steel Design - 2008
Example II-3, page II-148

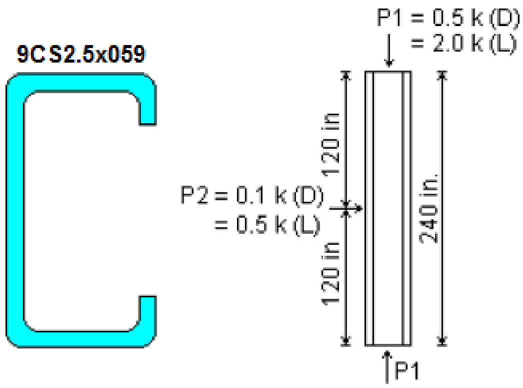
Comparison of Results:

Result type	STRAP	AISI
Design strength - M_n	18.68	18.7
Shear - V_n	4.39	4.38

5.2 AISI - Cold-formed column

Description:

A column, fully braced against lateral and torsional buckling, loaded axially and laterally:



Geometry:

- Steel: F_y = 55 ksi
- Section: 9CS2.5x059
- Section fully braced for lateral and torsional buckling
- k_x = 1.00, L_x = 240 in.

Loads:

As shown above.

Reference:

AISI Manual - Cold-formed Steel Design - 2008
Example III-1, page III-46

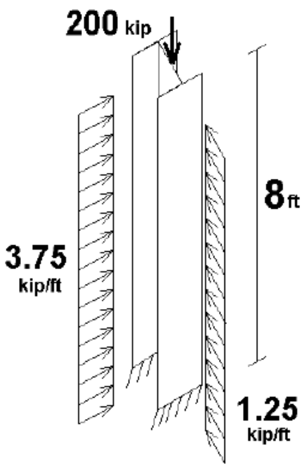
Comparison of Results:

Result type	STRAP	AISI
Design strength - M_n	8.67	8.67
Axial force - P_n	19.2	19.2
Combined - ASD	0.87	0.867
Combined - LRFD	0.87	0.869

5.3 AISC - Hot rolled column

Description:

Cantilever column, fixed at the bottom end, loaded in all three global directions:



Geometry:

Steel: F_y = 36 ksi
Ly = 8 ft.
Section = W14x45
$k_x = k_y = 2$
E = 29000 ksi

Loads:

as shown.

Results:

- V2 Shear:

  V= 30 kip

  $b/t_f = (0.5)(15.5)/1.09 = 7.11 \; = \; 1.1v(k_v\, E/F_y) = 1.1v(1.2x29000/36) = 34.2$

  $C_v = 1.0$

  $A_w = 2(b_f)(t_f) = 2(15.5)(1.09) = 33.79\ in^2$

  $V_n = 0.6F_yA_wC_v = 0.6 \cdot 36 \cdot 33.79 \cdot 1.0 = 730$ kip

  $V/(0.6V_n) = 30/(0.6 \cdot 730) = 0.07$

- V3 Shear:

  V= 10 kip

  $h/t_w = (11.42)/0.68 \; = 16.8 \; = \; 2.24v(E/F_y) = 2.24v(29000/36) = 63.57$

  $C_v = 1.0$

  $A_w = (d)(t_w) = (14.78)(0.68) = 10.05\ in^2$

  $V_n = 0.6F_yA_wC_v = 0.6 \cdot 36 \cdot 10.05 \cdot 1.0 = 217.1$ kip

  $V/(0.67V_n) = 10/(0.67 \cdot 217.1) = 0.07$

- M2 moment:

  M = 40 ft·kip

  $L_p = 1.76\, r_y\, v(E/F_y) = 1.76 \cdot 3.98 \cdot v(29000/36) = 198.9$ in = 16.57 ft

  $L_n = 8$ ft $< L_p$

$M_n = M_p = F_y \cdot Z_x = 36 \cdot 260 = 9360$ in·kip = 780 ft·kip

$M/(0.6M_n) = 40/(0.6 \cdot 780) = 0.09$

- M3 moment:

  M = 120 ft·kip

  $M_n \cdot M_p = F_y \cdot Z_y = 1.6F_yS_y = 36 \cdot 133 = 1.6 \cdot 36 \cdot 87.35$

  $M_n = 399 = 419.3$ ft·kip

  $M/(0.6M_n) = 120/(0.6 \cdot 399) = 0.50$

- Axial:

  P=200 kips

  $kl/r = 2 \cdot 8 \cdot 12/3.98 = 48.24 = 4.71v(E/F_y) = 4.71v(29000/36) = 133.6$

  $F_e = \pi^2E/(kl/r)^2 = \pi^2 \cdot 29000/48.24^2 = 123$

  $F_{cr} = [0.658^{\,Fy/Fe}]\ F_y = [0.658^{\,36/123}]\ 36 = 31.85$ ksi

  $P_n = F_{cr}\ A_g = 31.85 \cdot 42.7 = 1360$ kips

  $P/(0.6P_n) = 200/(0.6 \cdot 1360) = 0.245$

- Combined forces:

  $P_r = 200$ kip $M_{rx} = 1.02 \cdot 40 = 40.8$ $M_{ry} = 1.06 \cdot 120 = 127.2$

  $P_r/P_c = 0.245$

  $(P_r/P_c)\ [^8/_9 \cdot M_{rx}/M_{cx} + {}^8/_9 \cdot M_{ry}/Mc_y\ ] = 1.00$

  $(200/816)\ [^8/_9 \cdot 40.8/468 + {}^8/_9 \cdot 127.2/239.4] = 0.80 = 1.00$

STRAP detailed results:

DESIGN	EQUATION	FACTORS	VALUES	RESULT	Calculation:
V2 Shear (G2.1.b-i)	Vu/0.6Vn<1.00 Vn=0.6*Fy*Aw	Aw= 33.81	Vu = 30.00 Vn = 732.56	0.07	0.07
M3 Moment (F6-1) without LTB	M / 0.6Mn < 1.00	Z = 133.00	M = 120.00 Mn = 399.48	0.50	0.50
V3 Shear (G2.1.a)	Vu/Vn/1.5<1.00 Vn=0.6*Fy*Aw	Aw= 10.07	Vu = 10.00 Vn = 217.69	0.07	0.07
M2 Moment (F2-1) without LTB	M / 0.6Mn < 1.00	Z = 260.00	M = 40.00 Mn = 780.92	0.09	0.09
Axial Force (E3-1)	Pu / 0.6AgFcr < 1.00	(kL/r)x =30 (kL/r)y =48	Pu = 200.00 Ag = 42.70 Fcr = 31.90	0.24	0.245
Combined Forces (compress.) (H1-1a)	Pr/φPn + 8Mrx/9φMnx + 8Mry/9φMny < 1.00	Cmx= 1.00 Cmy= 1.00 Pex = 13641.67 Pey = 5328.78	Mrx = 40.96 Mry = 127.67 B1x = 1.02 B1y = 1.06	0.80	0.80