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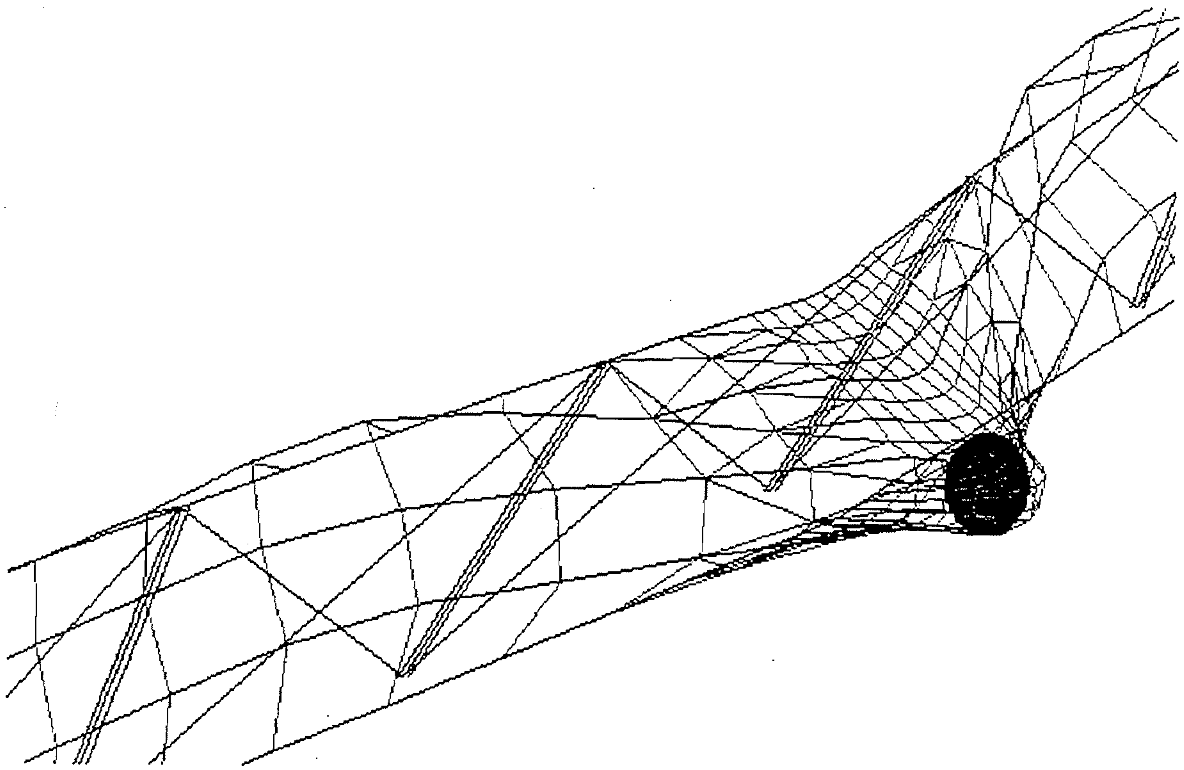

High-Capacity Flexpost Rockfall Fences

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December, 1992
With Addendum on Prototype Testing. May, 1994

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16. Abstract
Designs of high-capacity rockfall fences are developed through numerical simulations of rockfall impacts and through a prototype test. Based on the existing design of the Colorado DOT flexpost fence, three designs at 80,000 ft-lb rockfall capacity are developed. The three designs provide for fences of 10, 16 and 24 foot height, and all use steel gabion mesh for fence fabric. A fourth design using steel cable net for fabric on a 10 foot tall fence was constructed as a full-scale prototype and tested with freely falling boulders. The cable net design has a rockfall capacity of 125,000 ft-lb.

A description of flexpost fences, maximum forces in components of fences, sizes of components for the four designs of fences, computer models for numerical simulations, and results of simulations are presented. A summary of prototype tests is presented. A list of suppliers of cable and wire mesh products is provided.

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Abstract

Designs for high-capacity Flexpost rockfall barriers are reported. Five barrier designs using standard configurations of posts, stays, cables and mesh are studied. The designs cover a range of mesh weights, and barriers heights of 10, 16 and 24 feet. Each design is analyzed for response to four rockfall impact cases. Designs at three fence heights are proposed. Each has a rockfall capacity of 80,000 ft-lbs.

Introduction

The Colorado Department of Transportation has developed several new rockfall barriers in recent years. Among these is the CDOT Flexpost fence, a steel mesh and cable construction supported on spring-mounted posts which are capable of large elastic rotations about the base. Large rotations in posts make the barrier compliant and minimize impact forces. Elasticity in posts allows the barrier to rebound after rockfall impact. The Flexpost barrier resets itself after impact and is ready for subsequent rockfalls; a significant advantage over other rock fence designs.

The Flexpost fence is the product of a program of prototype tests and analytical studies which led, in 1991, to a standard design for a nominal 10 foot tall barrier with a rockfall capacity of 40,000 ft-lbs. This rockfall capacity is adequate for many hazard sites, and the Flexpost barrier is in use along I-70 in Glenwood Canyon. The 1991 design is a milestone of the program, but not an endpoint. It is clear that Flexpost barriers can be constructed both taller and with greater rockfall capacity. Moreover, the work leading to the 1991 design produced an analysis package for rockfall impact of flexible barriers. This analysis package is a unique resource and allows the study of stronger designs.

In 1992 the present analytical study of high-capacity Flexpost barriers was undertaken. Fence designs at three heights are analyzed for response to rockfall at 40,000 ft-lbs and 80,000 ft-lbs. Increased mass of fences are studied as well. The analytical study provides guidance on selection of fence components. It is found that high-capacity Flexpost barrier are feasible.

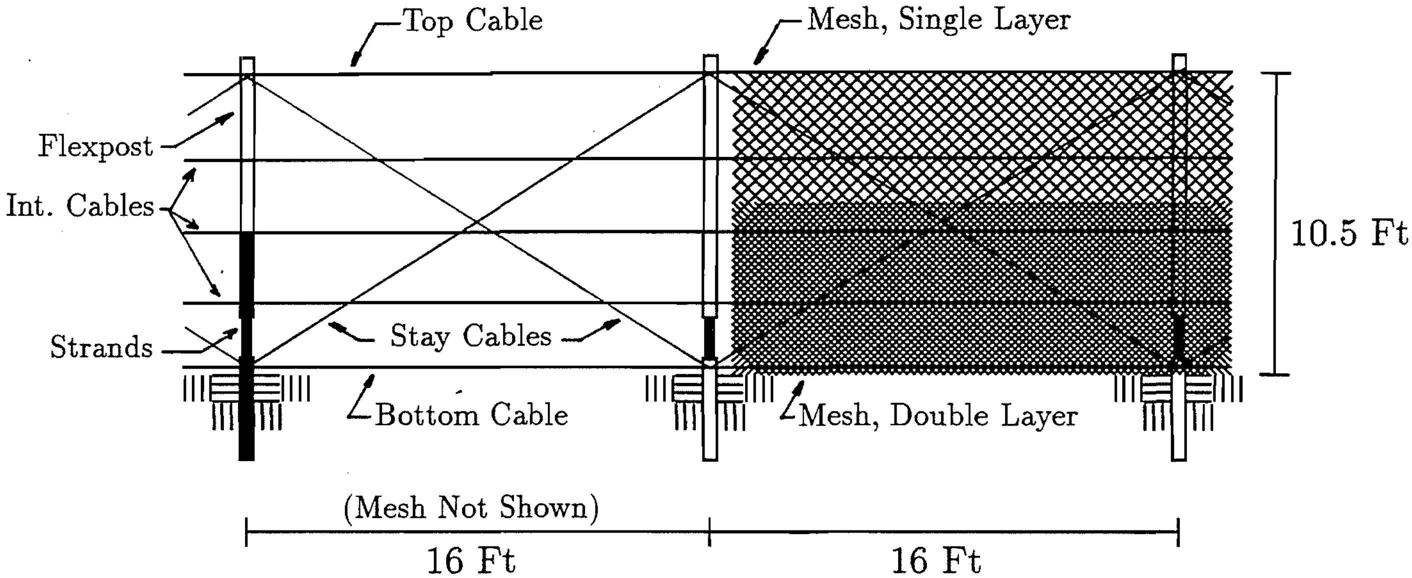


Figure 1: CDOT Flexpost Rockfall Fence

High-Capacity Flexpost Rockfall Fences

The Flexpost fence is a compliant barrier. It is constructed of steel gabion mesh reinforced by steel cables and supported on posts which can rotate about the base (Figure 1). Posts are kept upright by a spring composed of steel strands. When hit by a rock, the steel mesh is stretched taut and its tension provides a restraining force which halts the rock. This tension also causes rotations of the posts and an overall tilt of the barrier. The combined response is one of large deformation and low force. Bending resistance in Flexposts is not a significant actor in impact response. Details of the Flexpost fence and its performance are reported in Hearn 1991.

The Flexpost fence can fail to capture a rockfall if: a) the rock bounds over the barrier, or; b) a fence component fails. Component failures are most commonly a tensile failure of the mesh. An increase in rockfall capacity therefore requires:

- Increase in height of the barrier.
- Increase in strength of components, particularly the steel mesh.

Barrier height and strength can both be increased. Greater strength in mesh is achieved by using additional layers of gabion mesh or by using other steel fabric constructions such as cable nets. In either case the weight of the fence will be increased.

Modifications to the height of a Flexpost fence and to the strength (and weight) of its components will alter the dynamic response. In general, increased height means greater compliance and a reduction of impact forces. Increased component weight means increased inertial response and an increase in impact forces. These effects are opposed. The net change in impact response for barriers which are both taller and heavier must be investigated.

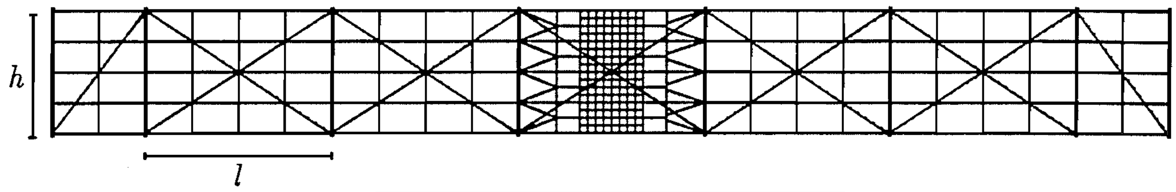
Towards that end analysis of response to rockfall impact has been performed for five designs of Flexpost rockfall fences. Three heights are examined: 10, 16 and 24 feet. For 10 foot tall fences, three weights of mesh are examined. The five designs are:

- Barrier A.S
  10 ft tall fence using a single layer of gabion mesh.
- Barrier A.D
  10 ft tall fence using two layers of gabion mesh.
- Barrier A.T
  10 ft tall fence using three layers of gabion mesh.
- Barrier B
  16 ft tall fence using a single layer of gabion mesh.
- Barrier C
  24 ft tall fence using a single layer of gabion mesh.

In all designs, the number of panels and the ratio of post height to post spacing have been kept the same as the 1991 design. Basic geometric data on models are shown in Figure 2.

Analysis

For rockfall analysis, Flexpost fences are modeled as lumped-mass systems. Elements for cables, stays and mesh are axial force, tension-only members. Impacts occur at the middle panel (Panel 4) of the models. In this panel a dense grid of members is used to model contact of the rock and the fence. A sparse grid of members is used for panels away from the impact (Figure 2). Additional detail on models is presented in Appendix I. The computational



Barrier	Flexpost No.	Flexpost h ft	Flexpost l ft	Overall Length ft
A.S	8	10	16	96
A.D	8	10	16	96
A.T	8	10	16	96
B	8	16	24	144
C	8	24	40	240

Figure 2: Flexpost Fence Designs

approach is an iterative, time marching procedure. All models have been analyzed for four rockfall impact cases:

- 40,000 ft-lb

  A 2000 lbs boulder with a velocity of 35.9 ft/s.

- 40,000 ft-lb

  A 4000 lbs boulder with a velocity of 25.4 ft/s.

- 80,000 ft-lb

  A 2000 lbs boulder with a velocity of 50.7 ft/s.

- 80,000 ft-lb

  A 4000 lbs boulder with a velocity of 35.9 ft/s

Results of Analysis

All rockfall analysis are continued to 1.8 seconds beyond the initial contact of the rock and the barrier. This time limit is arbitrary, but it does serve to capture the period of peak forces in all analyses with a reasonable continuation into the post-peak period.

Output from the analysis includes fence deflected geometry, members forces, contact forces and rock weights and position at 0.01 s intervals, the basic timestep of the computation. All analysis show qualitatively similar response. Contact forces with the rock increase as the barrier is engaged, and at the same time rock velocity decreases. Contact force reaches a peak as the forward velocity of the rock falls to zero.

Plots of forces acting on the rock and of rock velocity are shown in Figure 3 for an analysis of Model B for a 2000 lbs boulder with 80,000 ft-lbs kinetic energy. Notice that forward motion of the boulder (z component of the velocity) passes through zero and becomes negative. Boulders are typically thrown back out of the barrier; consistent with observed performance in field tests. Boulders are ejected by a release of tension in the mesh and cable, not by the spring of the Flexposts. Boulders in analysis are sufficiently heavy to hold posts down. Impact of the rock with the ground is evident in the jump in rock force at $t = 1s$. The ground surface is flat and level in the analysis.

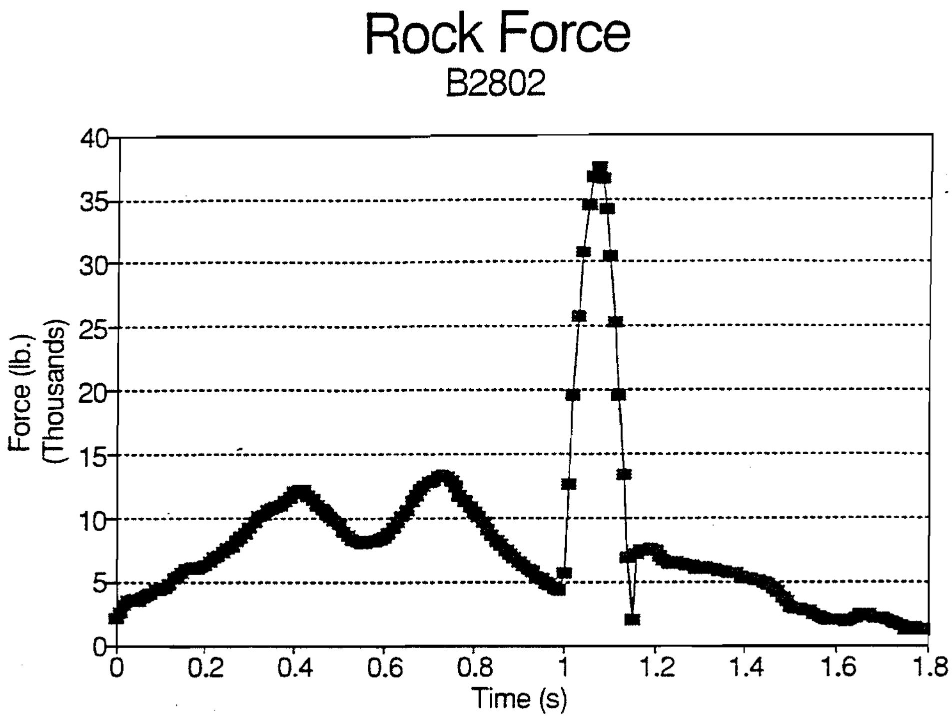
Figure 4 shows deflected shapes of the fence for Model B. Post processing of the output yields peak forces and time domain plots of force. Peak forces for bottom cables, top cables, stays and mesh are collected in Figure 5 for 80,000 ft-lb rockfall events. Taller barriers are clearly more compliant; forces in all major components decrease for taller fences. Increase in barrier mass causes a modest increase in component forces.

Peak forces in components for equal kinetic energies but different boulder weights are shown in Figure 6. There is limited influence of boulder mass on peak forces. Complete listings of peak force values are reported in Appendix II. Time domain plots of rock forces, rock velocities, components forces and reactions are presented in Appendix III.

Designs for High-Capacity Flexpost Fences

The standard configuration of the Flexpost fence may be used in high-capacity barriers. Taller fences are possible and greater component strength, where required, may be achieved through selection of cables and mesh. Analysis results for 80,000 ft-lb rockfall case have been used in the selection of components for high-capacity barriers (Figure 7).

In the proposed high-capacity barriers, greater mesh strength is achieved through use of multiple layers of gabion mesh. Gabion mesh is used in multiple horizontal segments to construct tall barriers. The 10' fence uses two horizontal segments; the 16' fence uses three



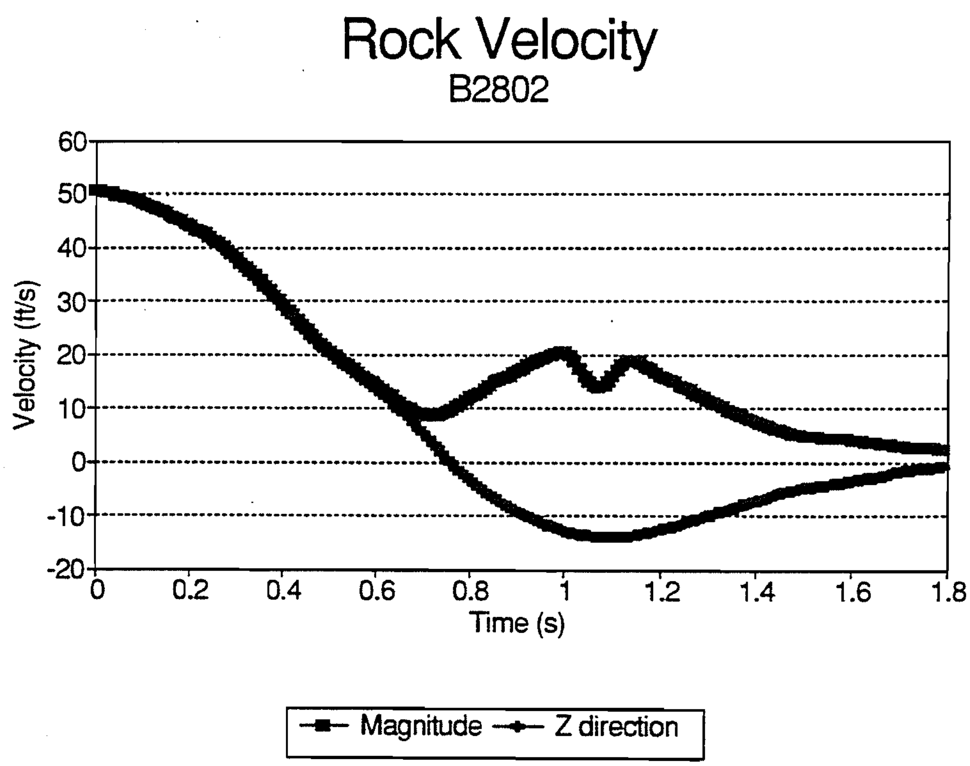


Figure 3: Rock Force and Velocity
Model B - 2,000 lbs. 80,000 ft-lbs

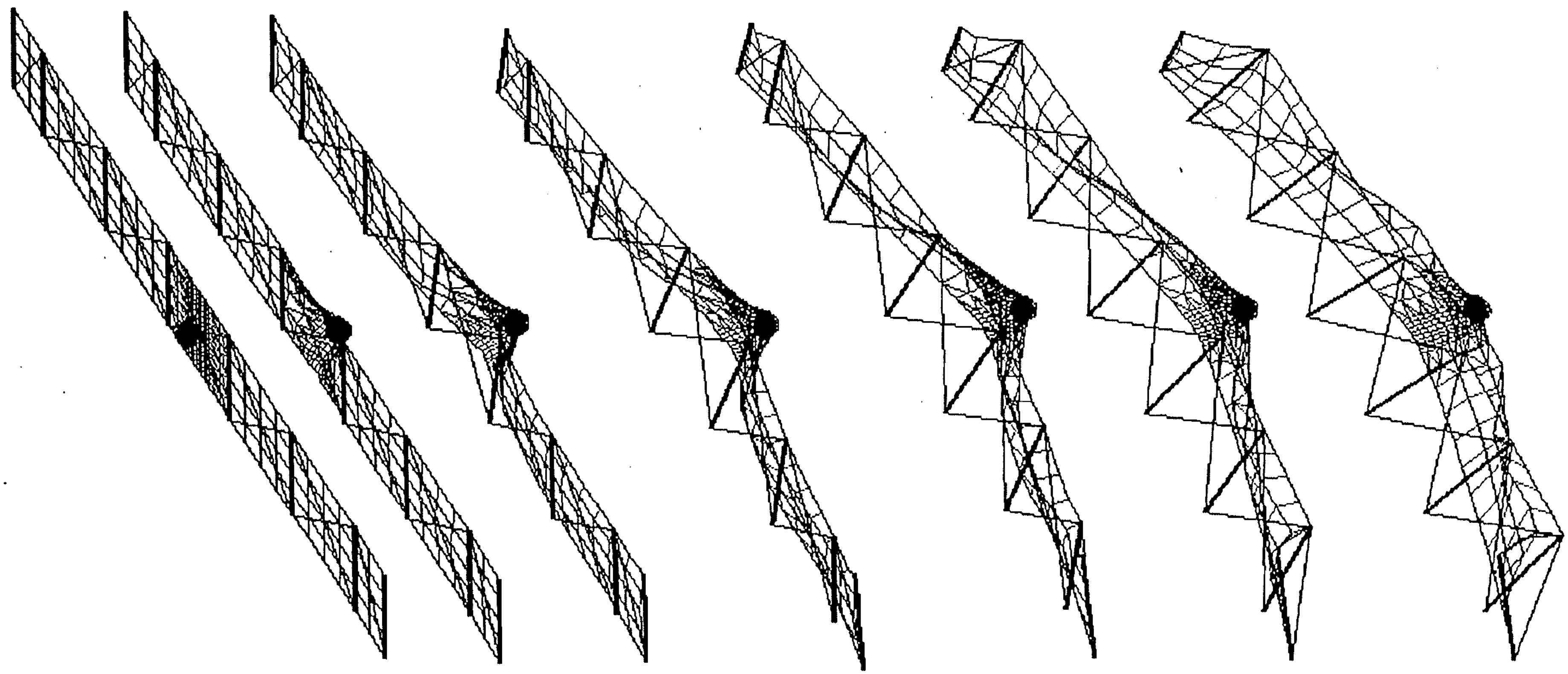


Figure 4: Flexpost Deflected Shapes
Model B - 2,000 lbs. 80,000 ft-lbs

Peak Forces in Components

Top Cable Force (pounds)

	Barrier Height 10'	16'	24'
Single Mesh	21,300	14,400	8,100
Double Mesh	22,300		
Triple Mesh	21,200		

Stay Force (pounds)

	Barrier Height 10'	16'	24'
Single Mesh	14,200	13,300	10,700
Double Mesh	15,900		
Triple Mesh	17,900		

Bottom Cable Force (pounds)

	Barrier Height 10'	16'	24'
Single Mesh	37,700	25,300	21,800
Double Mesh	41,000		
Triple Mesh	42,100		

Mesh Force (pounds/foot)

	Barrier Height 10'	16'	24'
Single Mesh	3,800	2,200	1,500
Double Mesh	3,800		
Triple Mesh	3,700		

Figure 5: Peak Forces
80,000 ft-lb Rockfalls

Flexpost Fences: 80,000 ft-lb Capacity

Component	Barrier Height 10'	16'	24'
Posts	3" Dia	3" Dia	4"[1] Dia
Top Cable	Bridge Rope 1/2" Dia	Aircraft Cable 7/16" Dia	Aircraft Cable 7/16" Dia
Bottom Cable	Bridge Rope 3/4" Dia	Bridge Rope 5/8" Dia	Bridge Rope 1/2" Dia
Interior Cables	Aircraft Cable 1/4" Dia	Aircraft Cable 1/4" Dia	Aircraft Cable 1/4" Dia
Stays	Bridge Rope 1/2" Dia	Aircraft Cable 7/16" Dia	Aircraft Cable 5/16" Dia
Mesh (6' width)	Two Segments Top: Double Bottom: Triple	Three Segments Top: Single Mid: Single Bottom: Double	Five Segments Top: Single Mid 1: Single Mid 2: Single Mid 3: Double Mid 4: Double

1. To be confirmed in tests.

Figure 7: High-Capacity Fences

segments; the 24' fence uses five segments. Greater strength in cables is achieved through larger cable size.

Bottom cables are the largest cables components and it may be necessary to use bridge rope rather than aircraft cable to obtain the needed size. For cable sizes up to 7/16" diameter, a galvanized aircraft cable is suitable. For larger cable diameters, 7x7 galvanized bridge rope with an independent wire rope core (IWRC) is suitable. Haul ropes and other wire ropes with fiber cores may be used, but larger diameter ropes will be needed. Fiber core ropes have lower breaking strength than IWRC ropes.

The current 3" diameter Flexpost will be adequate to support the proposed 10' and 16' high-capacity barriers. The 24' barrier, because of its great dead weight, will need a larger post. The bending stiffness of a larger Flexpost should be confirmed in tests, but it is likely that a 4" diameter post will be suitable.

Forces on post foundations are nearly double for the high-capacity barriers. The 40,000 ft-lb fence imposes shears on foundations of about 27,000 lbs. An 80,000 ft-lb barrier increases the demand to 54,000 lbs. These loads, though high, are of very short duration, being above 10,000 lbs for only 0.8 second on average. Post foundations have performed well in tests.

Alternative Mesh Materials

Gabion mesh has performed well in field tests and in Flexposts in service. Gabion mesh is considered to be an excellent choice for the high-capacity fences proposed in this study. Other products are available, however, and could be used. Cable nets constructed of wire rope are used in rock fences. Chain link mesh is also used in rock fences, usually for light duty. Cable nets and chain link mesh could be attached to Flexposts in the same manner as gabion mesh.

The likely performance of alternate mesh materials may be predicted from a knowledge of mesh strength and mesh weight. A comparison of weights and probable strengths of gabion mesh, cable net and chin link mesh are shown in Figure 8. Two materials are considered here:

Mesh		Weight psf	Strength plf
Gabion	2.5"x3.25", 2.0mm	.29	2,000
Cable Net	8"x8", 5/16"	.88	12,000[1]
Chain Link	2"x2", 6 gage	1.15	13,000[1]

1. Based on wire area

Figure 8: Mesh Materials

Cable Net

Cable net for Flexpost fences is an 8"x8" grid of 5/16 in diameter wire ropes. This is the construction used in many of the rock fences built by Brugg and it is the material tested by California DOT in their 1990 test of rock fences (Smith & Duffy 1990). The cable net has a weight approximately equal to three layers of gabion mesh and provides a greater strength. For a 80,000 ft-lb rockfall capacity, the cable net may be used directly in place of the gabion mesh. Interior cables used to reinforce gabion mesh are not required for cable nets. Top and bottom cables as well as stay cables are required. In addition, a finer mesh is needed in parallel to capture debris which might pass through the 8" square openings of the cable net.

Chain Link Mesh

Chain link is available in a variety of wire diameters and cell sizes. For rockfall applications a 2"x2" weave of 6 gage wire is common. This material in single layer is relatively heavy and offers a large wire area per foot width of mesh. Tensile strength associated with the area is comparable to that of cable nets. On the basis of preliminary weights and strength review it appears that chain link is suitable for use of the Flexpost fence. Since this is a mass-produced material, it may offer a cost savings. The single twist weave may allow chain link to unzip if individual wires are damaged in a rockfall impact.

Summary

High-capacity Flexpost fences are feasible and may be constructed as heavier versions of the standard cable, stay, and post configuration now in use. The increased mass of high-capacity barriers does cause an increase in component forces during rockfall impact. The increase is modest however and is not an impediment. Taller barriers are feasible, and offer the advantage of greater compliance.

The present 3" Flexpost is adequate to support 10' and 16' tall high-capacity fences. A 24' fence will require a stronger post. Post foundations will experience greater loads in high-capacity barriers.

References

Hearn,G. (1991). "CDOH flexpost rockfall fence." Colorado Hwy. Dept., Rpt. CDOH-R-UCB-91-6, Denver, CO.

Smith,D.D., and Duffy,J.D. (1990). "Field tests and evaluation of rockfall restraining nets." CALTRANS, CA/TL-0/05, Sacramento, CA.

Addendum
Testing of a Prototype High Capacity Flexpost Fence

A prototype 10 foot tall high-capacity flexpost fence was constructed and tested on October 2, 1993. Among the high-capacity fence designs that are proposed (at fence heights of 10, 16 and 24 feet), the 10 foot design will experience the greatest forces during impact, and therefore requires the heaviest cables, stays and fabric. For this reason the 10 foot prototype is the most demanding test among the set of three designs. Moreover, the 10 foot prototype admits the study of the possible retrofit of standing flexpost fences. If it becomes necessary to increase the strength of 40,000 ft-lb fences, it is worthwhile to demonstrate how a standing fence may be improved without being entirely replaced.

The 10 foot tall prototype was tested with freely falling boulders at Rifle, Colorado. This is the same site used for previous tests of flexpost fences (Hearn 1991), for tests of tire attenuators (Barrett, et.al. 1989) and for tests of mechanically stabilized earth wall barriers (Parsons DeLeuw 1992). As in previous tests, boulders are dropped from the top of the slope. The progress of each boulder and the impact with the barrier are recorded on videotape. Videotapes are later processed to recover rock velocity, point of impact with the barrier, and an assessment of the barrier response. The fence is inspected for damage after each impact.

A schematic of the prototype flexpost fence is shown in Figure 9. Apart from the use of cable net and the substitution of heavier top, bottom and stay cables, this is a standard form of the flexpost fence. The prototype is constructed of cable net panels lined with a single layer of gabion mesh and supported by top and bottom cables. The top cable is attached to each post top, and posts are joined to each other with diagonal cable stays. The bottom cable (two parallel 1/2" diameter ropes) is loosely attached to post bases by slack cable tethers. These tethers were removed during the course of the test. Cable net panels are a Brugg low-impact net of 5/16" cables joined by mechanical fasteners in a 8"x8" right rectangular grid. Net panels are approximately 10 ft x 16 ft. Panels are attached to top and bottom cables by a 5/16" seam rope, and adjacent panels are joined by similar seam ropes. Nets are not attached to stay cables. Flexposts for the prototype are standard 3" diameter posts using a group of 7-wire strands as the flexing element.

Fifteen boulders were dropped at the prototype resulting in ten impacts. The size of boulders that hit the fence ranged from a 3 foot diameter boulder weighing 1300 lbs to a 5.5 foot diameter boulder weighing more than 8900 lbs. Kinetic energies at impact ranged from 6490 ft-lb to 746,000 ft-lb. A log of the tests is presented in Figure 10. A map of the impact locations is shown in Figure 11. Among the significant tests, the following are noted:

1. The prototype stopped a boulder at 122,500 ft-lbs (Test 12) with no damage to itself.
2. The prototype stopped a boulder with a kinetic energy of 366,500 ft-lbs (Test 11) with moderate, but not disabling, damage.
3. The prototype was seriously damaged by an impact at 746,000 ft-lbs (Test 15), and

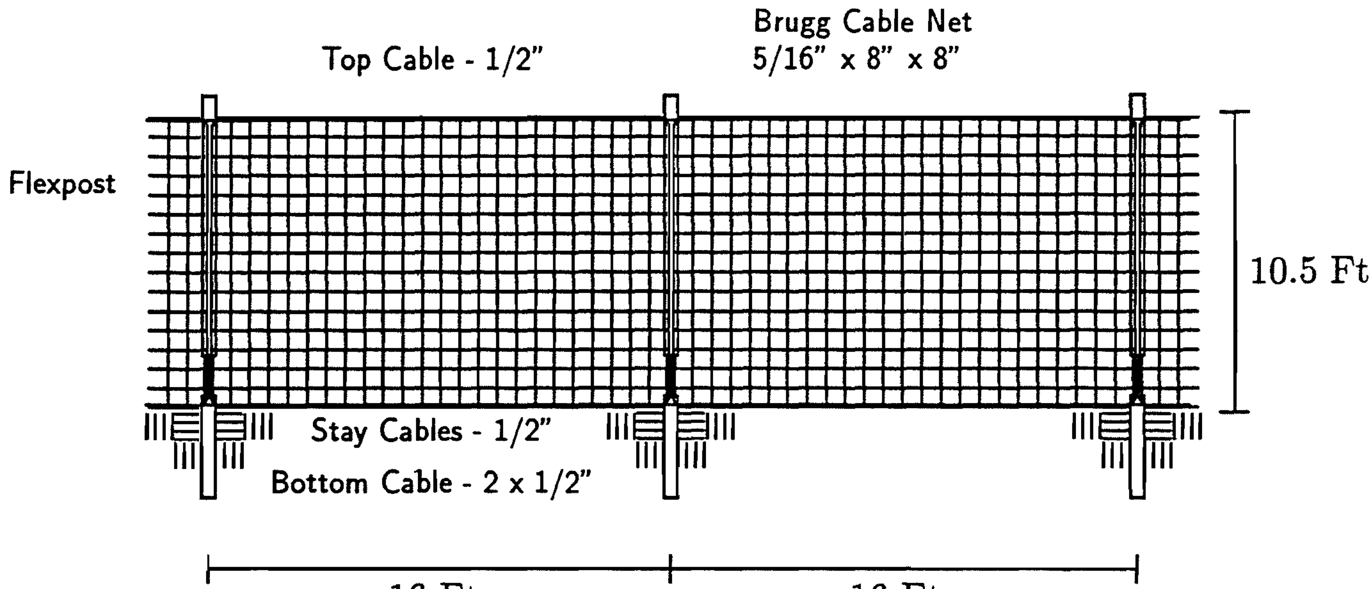


Figure 9: Prototype 100,000 ft-lb Flexpost Rockfall Fence Using Cable Net

failed to stop the boulder in this impact.

On the basis of these tests, this design of the flexpost fence is rated at a rockfall capacity of 125,000 ft-lbs.

The rockfall capacity of the flexpost fence is a function of boulder size (diameter) as well as kinetic energy. The flexpost fence traps boulders by forming a pocket of fence fabric around boulders. When rock diameter is large, or when the fabric is constrained and cannot deform freely around the boulder, only a shallow pocket will form. Large diameter boulders can drive the fence to the ground, and roll over it without stopping. This was observed for the prototype in Test 9 when a 3.9 foot diameter boulder rolled over the fence at a post location. After this impact the compliance of the fence fabric was increased by removing cable tethers connected to the bottom cable. Without tethers, the fabric can swing away from the posts at the bottom, and more readily form a pocket to capture boulders. After the tethers were removed, the prototype stopped boulders in Tests 11 and 12. These boulders were 3.8 ft in diameter and 4.6 ft in diameter, respectively. Though improved, the fence still has a limit on boulder diameter that it can capture. In Test 14 a boulder with a diameter of 5.5 ft rolled over the fence. On the basis of these tests, the maximum size boulder that the fence can capture is about 4 foot in diameter.

It was observed that the prototype did not free itself of boulders after impact. This is in contract to the original 40,000 ft-lb fence which was often able to eject rocks from its fabric after impacts. The presence of a boulder in the fence means that the height of the fence is reduced, and that the fabric is constrained. Both conditions reduce the rockfall capacity of the fence. Removal of the boulder is necessary. High-capacity flexpost fences may require maintenance after any sizable rockfall event.

Test No.	Rock ID	Weight *lbs*	Vel ft/s	ω rad/s	KE_{Trans} $ft-lb$	KE_{Rot} $ft-lb$	KE_{Total} $ft-lb$	Observation
1	F	1302	16.7	18.9	5640	4970	10610	Rock Stopped.
2	I	1518	0.0	0.0	0	0	0	No Impact.
3	H	1737	20.5	10.9	11300	2810	14110	Rock Stopped.
4	48	1855	12.6	8.8	4580	1910	6490	Rock Stopped.
5	35	1850	40.8	25.2	47800	17400	65200	Rock Stopped.
6	96	2834	0.0	0.0	0	0	0	No Impact.
7	K	1737	53.0	27.0	75900	14800	90700	Rock Stopped. Minor damage to net.
8	80	3415	0.0	0.0	0	0	0	No Impact.
9	79	4129	50.1	30.1	161000	87100	248100	Rock Not Stopped.
10	33	5040	0.0	0.0	0	0	0	No Impact.
11	102	4646	61.4	30.4	273000	93500	366500	Rock Stopped. Moderate damage.
12	83	6554	29.4	12.9	88200	34300	122500	Rock Stopped.
13	93	8918	0.0	0.0	0	0	0	No Impact.
14	92	8918	45.5	16.6	287000	90800	377800	Rock Not Stopped.
15	90	8975	62.9	24.6	551000	195000	746000	Rock Not Stopped. Major damage.

Notes on Rock Tests

1 Rock slowed as it appoached the fence.
2 Rock halted before reaching the fence.
3 Rock slowed as it appoached the fence.
4 Rock slowed as it appoached the fence.
5 No damage.
6 Rock halted before reaching the fence.
7 Crimped splice in net pulled open.
8 Rock halted before reaching the fence.
9 Rock rolled over fence at post.

Bottom cable tethers removed after Test 9.

10 Rock astray.
11 Stay cable broken. Several net connectors opened. Many hog ties at top broken.
12 Rock split. One fragment stopped.
13 Rock astray.
14 Rock rolled over fence at post.
15 Top cable and seam rope broken.

Figure 10: Summary of Tests of Prototype - October 2, 1993
125,000 ft-lb Flexpost Fence

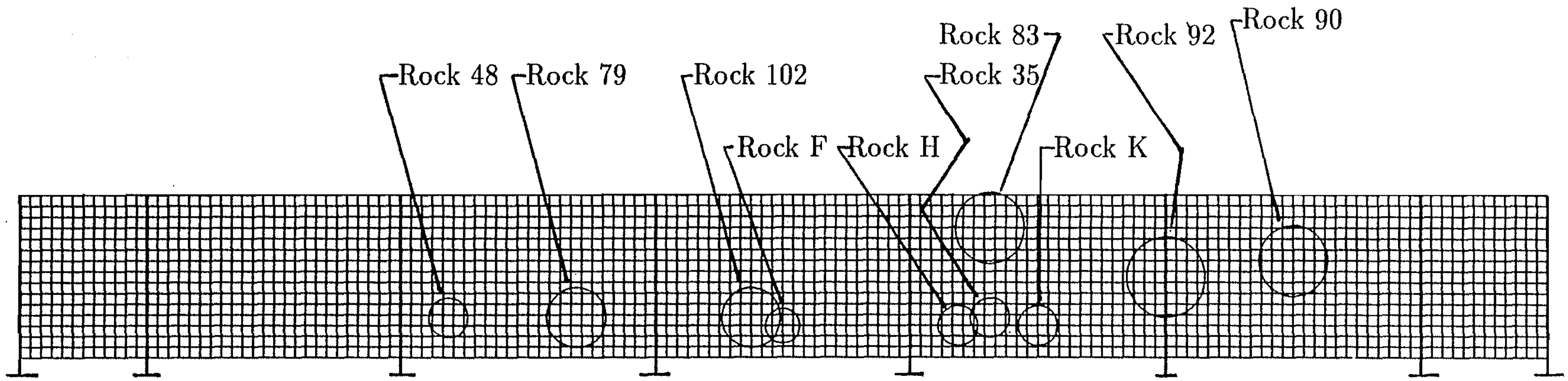


Figure 11:Map of Rock Impacts
Prototype Test October 2, 1994
125,000 ft-lb Flexpost Fence

In summary, the prototype tests indicate that the rockfall capacity of the fence is 125,000 ft-lb, that boulders can be as large as 4 feet in diameter, and that large boulders must be removed from the fence after impact. Overall the prototype performed well. The 10 foot flexpost fence constructed with cable nets is a strong and reliable rockfall barrier.

A Note on Brugg Cable Nets

The prototype flexpost fence tested at Rifle in 1993 was constructed with a Brugg cable net. Brugg Cable Products developed sturdy and versatile rockfall protection fences using cable nets in the 1970s and introduced these nets to the United States in the 1980s. The California Department of Transportation has been a leader in the testing and use of Brugg rockfall fences. Reports by Smith and Duffy (1990) and by Duffy (1992) are among the best sources of information on rock fences in general and on Brugg fences in particular. In addition, a test of Brugg low-impact net is reported by Kane et.al (1993).

Brugg cable nets are constructed of two orthogonal layers of parallel cables making a net with square openings. The two layers of cables are joined at all intersections with metal crimps. Each crimp joins two cables (one from each layer), and each crimp exerts a small contact force between cables. Brugg cable nets are constructed in rectangular panels, a typical size is 10 feet tall by 16 feet long (20 feet long for low-impact nets). The panels are completed by perimeter cables that are woven into the net openings. Perimeter and net cables are spliced where necessary by a crimped friction splice that is different from, and heavier than, the net crimp connectors. Brugg nets are constructed in what may be termed 'right' and 'skew' configurations. Right nets are constructed with net cables oriented at right angles to perimeter cables. Skew nets have net cables oriented at 45 degrees to the perimeter cables.

The strength of Brugg nets can be varied by the choice of orientation of net cables (right or skew) and by the spacing between net cables. In tests of 140,000 ft-lb fences, Duffy (1992) used a skew configuration net with 5/16" diameter cables in a 8"x8" grid. Stronger nets use a smaller grid spacing. Duffy reports that a 220,000 ft-lb net uses a 6"x6" grid, and that a 360,000 ft-lb net uses a 4"x4" grid. All nets are fabricated with 5/16" cables. Tests by Kane et.al. (1993) used a right configuration net of 5/16" cables in a 8"x8" grid and showed a limiting rockfall capacity of 66,000 ft-lb.

The flexpost fence prototype of 1993 used a Brugg low-impact net similar in construction to the net tested by Kane. Brugg cable nets performed adequately in flexpost prototype test. The following observations should be noted, however. A Brugg net panel failed at a splice in a net cable in Test 7 at a kinetic energy of 90,700 ft-lb. This splice was not able to develop the strength of the cables it joined. Brugg crimp connectors opened and detached at loads below the strength of the cables in the net. After repeated impacts, a net may require repair or replacement due to the loss of crimp connectors. Cables are durable, however. The cables in nets survived multiple impacts with no visible fraying or wear. Flexposts make efficient use of cable nets. This prototype flexpost fence is rated at 125,000 ft-lbs. The same net used on rigid posts is rated, by Brugg, at 50,000 ft-lb (Brugg 1993).

Recommendations for Use of High Capacity Flexpost Fences.
Numerical studies have produced designs for high capacity flexpost fences that provide for a nominal 80,000 ft-lbs rockfall capacity in fence heights of 10, 16 and 24 feet using a gabion mesh as the fence fabric. In addition, a prototype 10 foot tall fence using a cable net fence fabric has been constructed and tested. This cable net fence has a rockfall capacity of 125,000 ft-lb.

The rockfall capacity of flexpost fences is a product of both the strength of the materials used to construct the fence and of the compliance and mobility of the design. It is found in this study of flexpost fences, that tall fences are very compliant and offer much increased rockfall capacity without an increase in the strength or size of components of the fence. Shorter fences are less compliant. For short fences, increased rockfall capacity is achieved by increased strength in cables and fence fabric.

As a result of this study, five designs of flexpost fences have been developed. These are:

1. The standard flexpost fence at 10 foot height using gabion mesh and rated at 40,000 ft-lbs kinetic energy.
2. High capacity 80,000 ft-lb flexpost fences using gabion mesh at 10 foot height.
3. High capacity 80,000 ft-lb flexpost fences using gabion mesh at 16 foot height.
4. High capacity 80,000 ft-lb flexpost fences using gabion mesh at 24 foot height.
5. High capacity 125,000 ft-lb flexpost fences using cable nets at 10 foot height.

These designs are ready for use.

The rockfall capacity of high-capacity flexpost fences must be stated in terms of both limiting kinetic energy and limiting diameter of boulders. Prototype tests indicate that boulders as large as 4 feet in diameter can be stopped by 10 foot tall flexpost fences. It is important to construct these high-capacity fences without the use of tethers at the bottom cable. In addition, large rocks are observed to remain in flexible barriers, impairing their performance in subsequent rockfalls. High-capacity flexpost fences must be kept cleared of debris.

Further increases in the capacity of flexpost fences are possible. The tools for numerical simulation that have been developed in this and in previous studies allow for the rapid examination of stronger fences. Two features of the present flexpost fence should be particularly addressed in continuing development. First, taller designs should be emphasized. Higher rockfall capacity means that flexpost fences must be able to capture larger diameter boulders. Taller fences will be able to do this. Second, a stiffer post is needed to support the dead weight of taller fences, and to provide a better opportunity for flexpost fences to expel large boulders after impact.

References

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2. Brugg Cable Products (1993). "Low impact safety barriers." Brugg, Santa Fe, NM.
3. Duffy,J.D. (1992). "Field tests of flexible rockfall barriers." Brugg Cable Products, Santa Fe, NM.
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5. Kane,W.F., Fletcher,D.Q. and Duffy,J.D. (1993). "Low-impact rock net testing, performance, and foundation design." in *Transportation Facilities through Difficult Terrain*, J.T.H.Wu, R.K.Barrett, eds., Balkema, Rotterdam, 453-464.
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7. Smith,D.D. and Duffy,J.D. (1990). "Field tests and evaluation of rockfall restraining nets." CA/TL-90/05. CalTrans, Sacramento, CA.

Appendix I
Analytical Models

Five models of Flexpost fences have been prepared and analyzed for rockfall impact. The models represent fences o 10 ft 16 ft and 24 ft heights. All are similar in form to the prototype tested in Rifle in August, 1990. That is, all models include eight Flexposts and a ratio of post spacing to post height of about 1.6. Posts are beam elements. Cables and stays are tension-only members with zero bending stiffness. Mesh is also modeled as tension-only members with zero bending stiffness. The area and weight of mesh members is determined by the mesh material and by the tributary width of mesh for the member. Fence mass is lumped in fence nodes.

Each model is formed of a basic grid of members which includes all cable lines with a reasonable number of nodes per panel. One panel in each model is enhanced by a 1 ft x 1 ft grid of members.

This enhanced region is for contact with the boulder. In the analysis, the boulder and the barrier interact through an identification of nodes in contact with the rock surface and an assignment of contact forces.

General views of the models are shown in Figure I-1 and I-2. Model A has been used in three forms to study the relative performance of fences with single layer of mesh (Model A.S), with two layers of mesh (Model A.D), and with three layers of mesh (Model A.T). All three 'A' models have the same topology of nodes and members. The additional mesh layers are introduced through an increase of mesh member area and weight.

Node locations, cable members, and mesh members for each model along with detailed views of the basic grids and contact grids are shown in Figures I-3 to I-8. Member properties are shown in Figures I-9 to I-13.

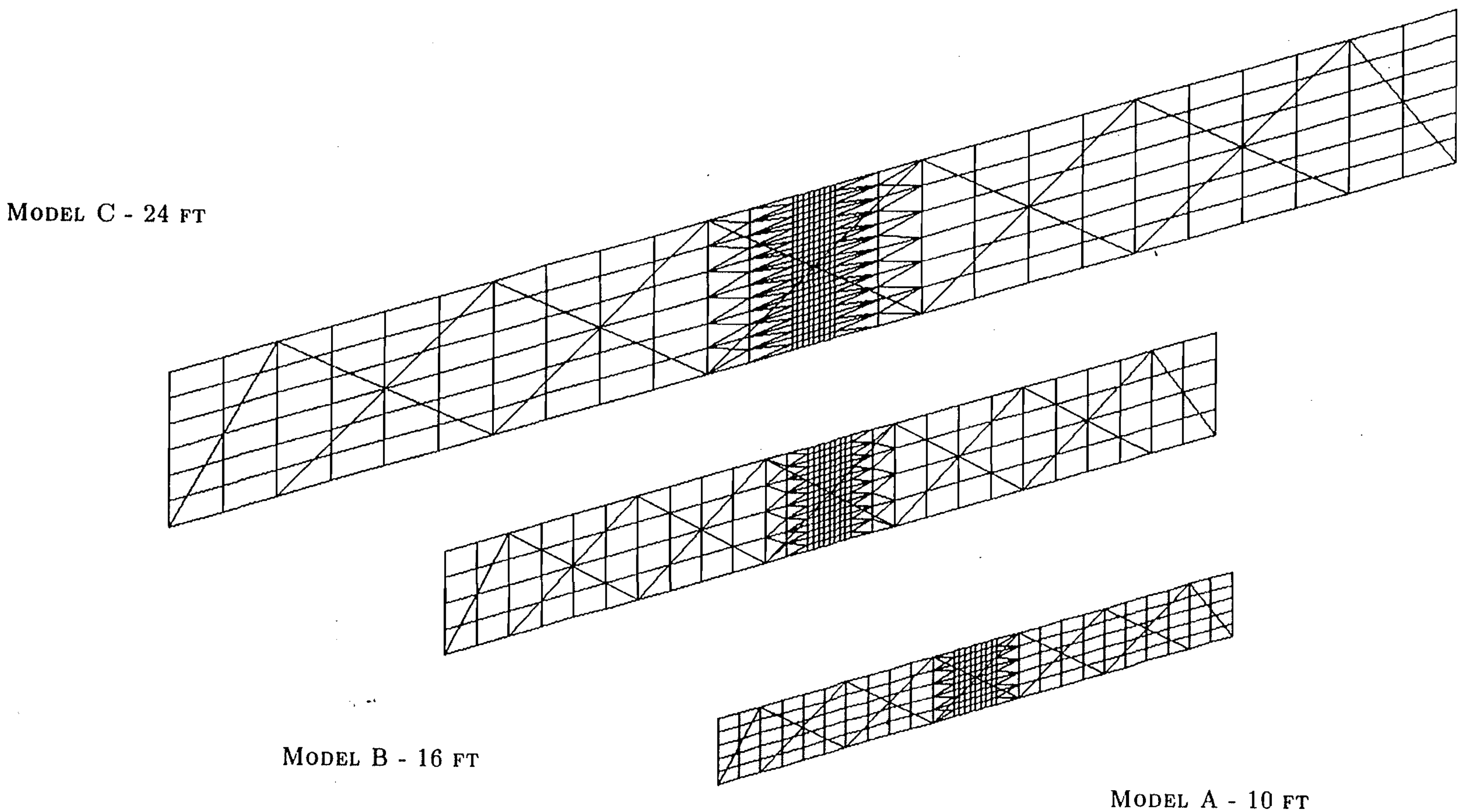


Figure I-1: Flexpost Fence Models - General Views

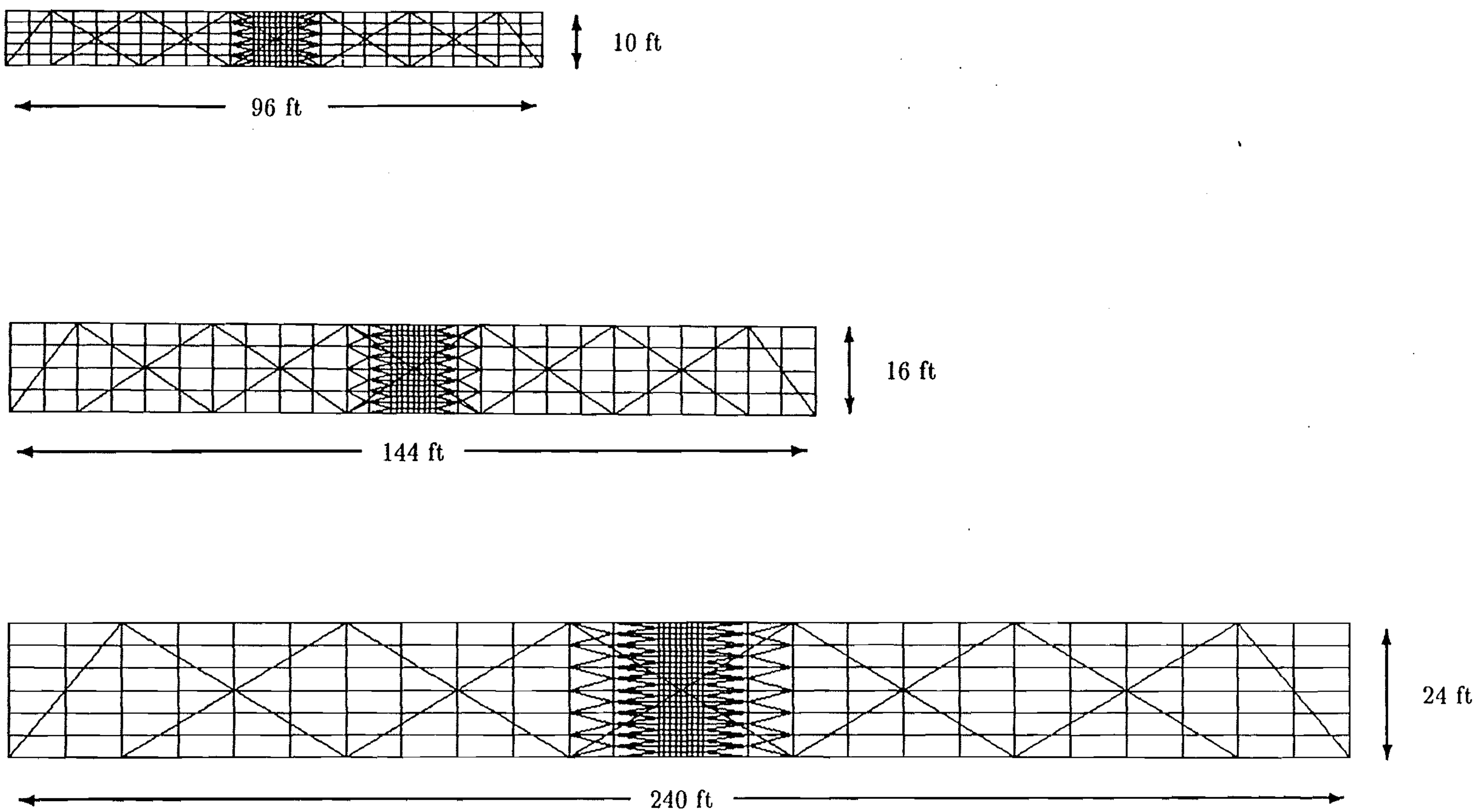
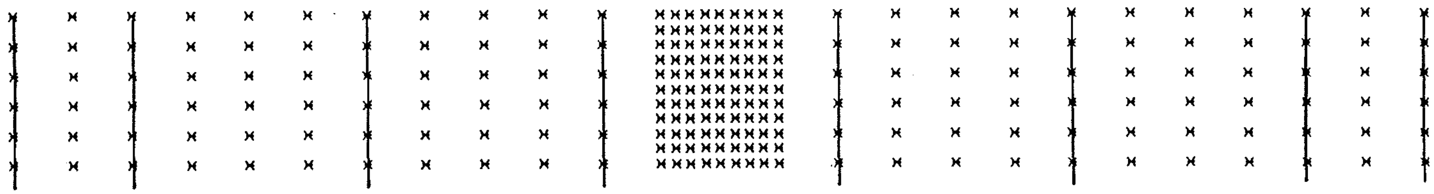
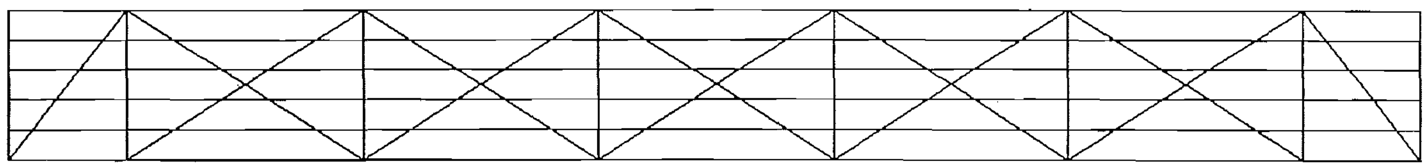


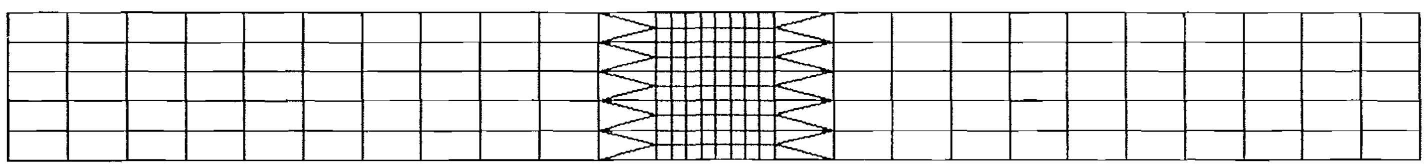
Figure I-2: Models A, B and C



MODEL A - NODE LOCATIONS



MODEL A - CABLES, STAYS & POSTS



MODEL A - MESH MEMBERS

Figure I-3: Model A - 10 ft Fence

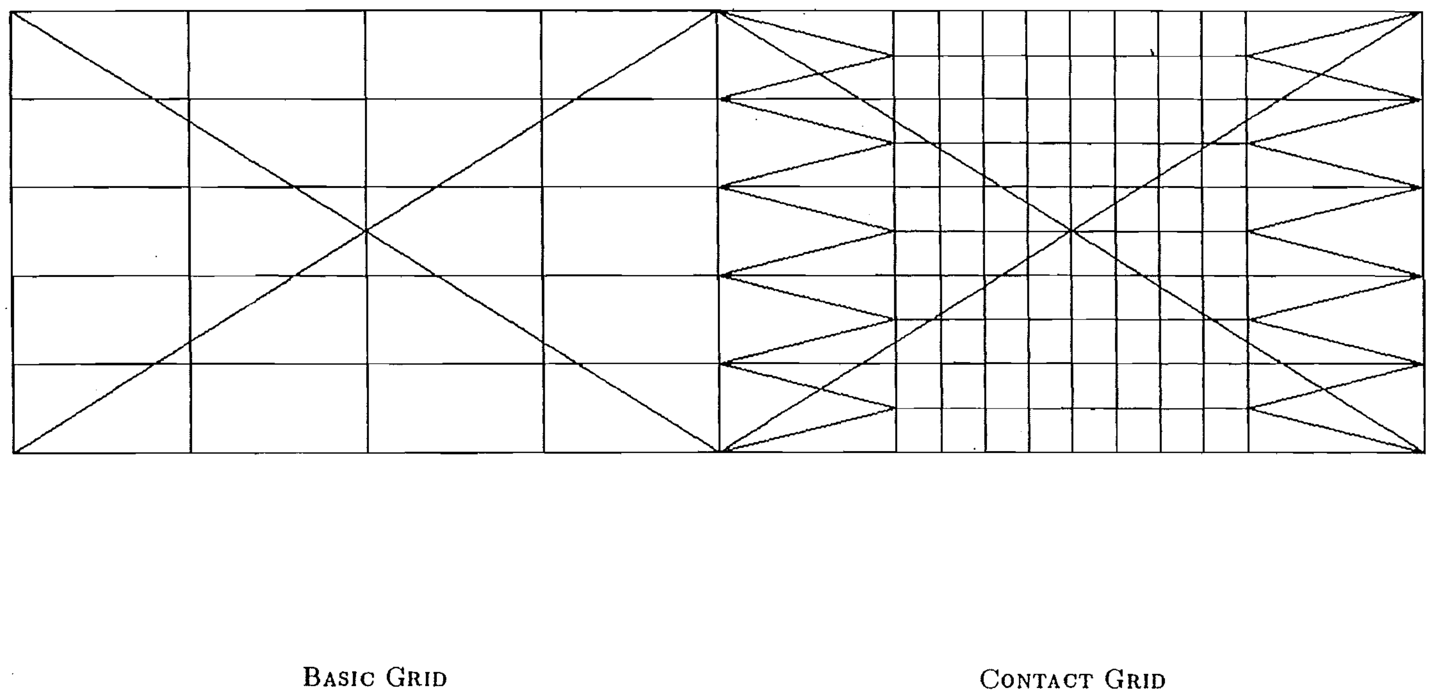
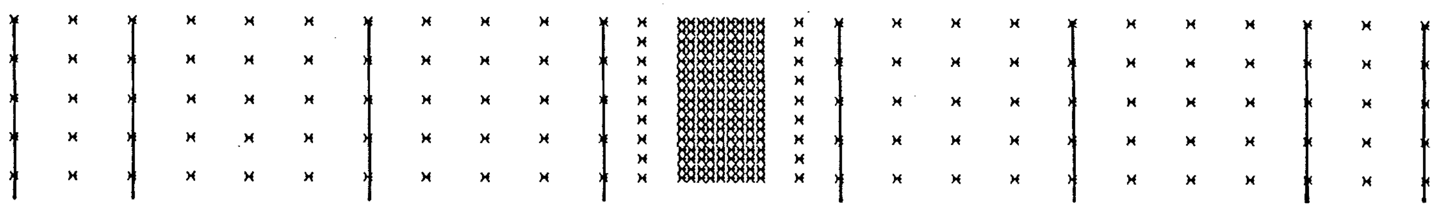
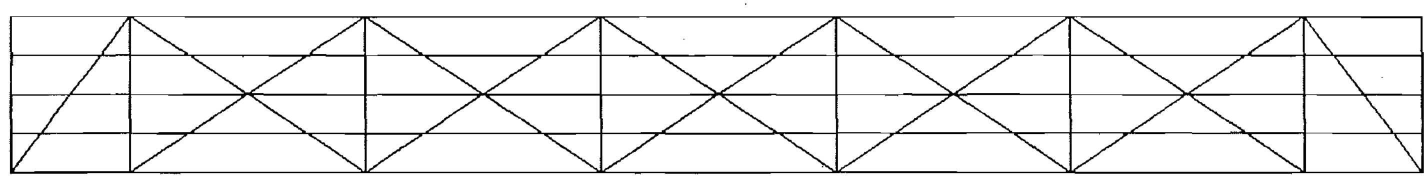


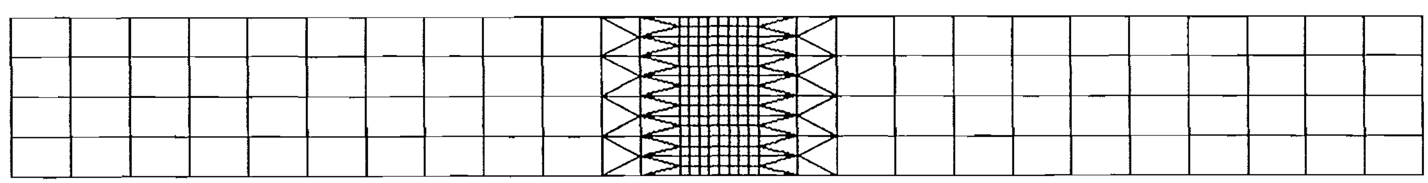
Figure I-4: Model A - 10 ft Fence



Model B - Node Locations

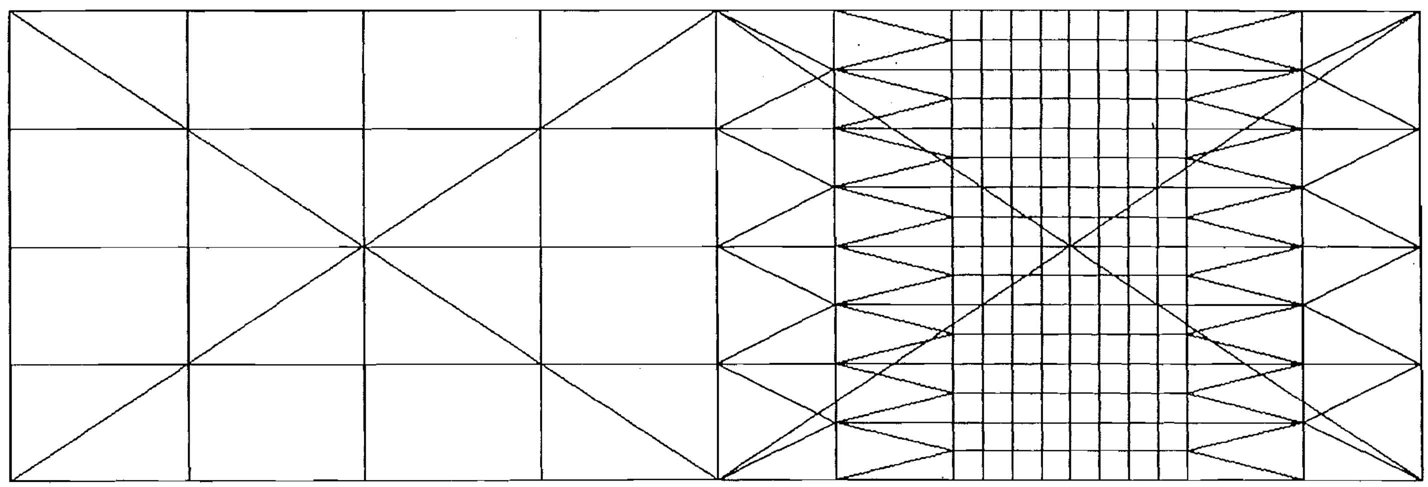


Model B - Cables, Stays & Posts



Model B - Mesh Members

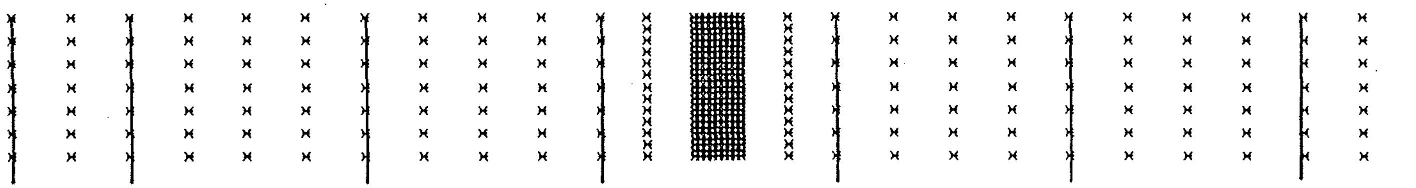
Figure I-5: Model B - 16 ft Fence



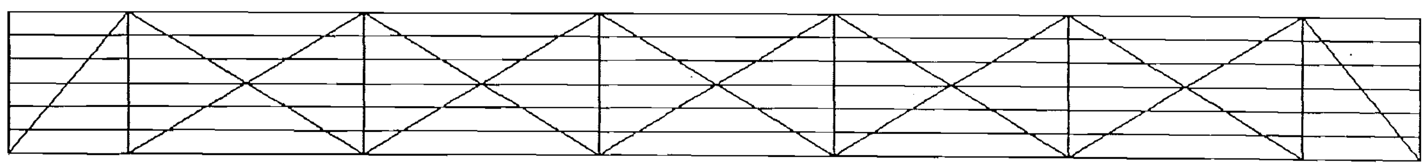
Basic Grid

Contact Grid

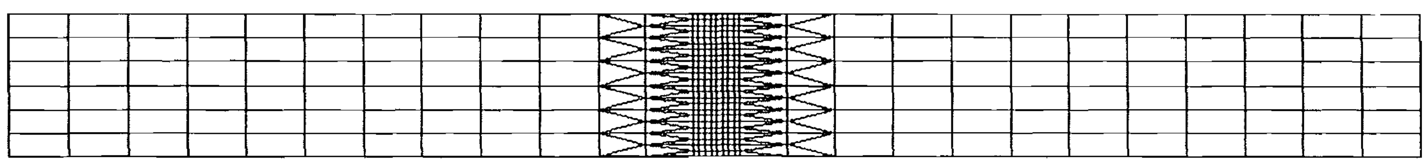
Figure I-6: Model B - 16 ft Fence



Model C - Node Locations



Model C - Cables, Stays & Posts



Model C - Mesh Members

Figure I-7: Model C - 24 ft Fence

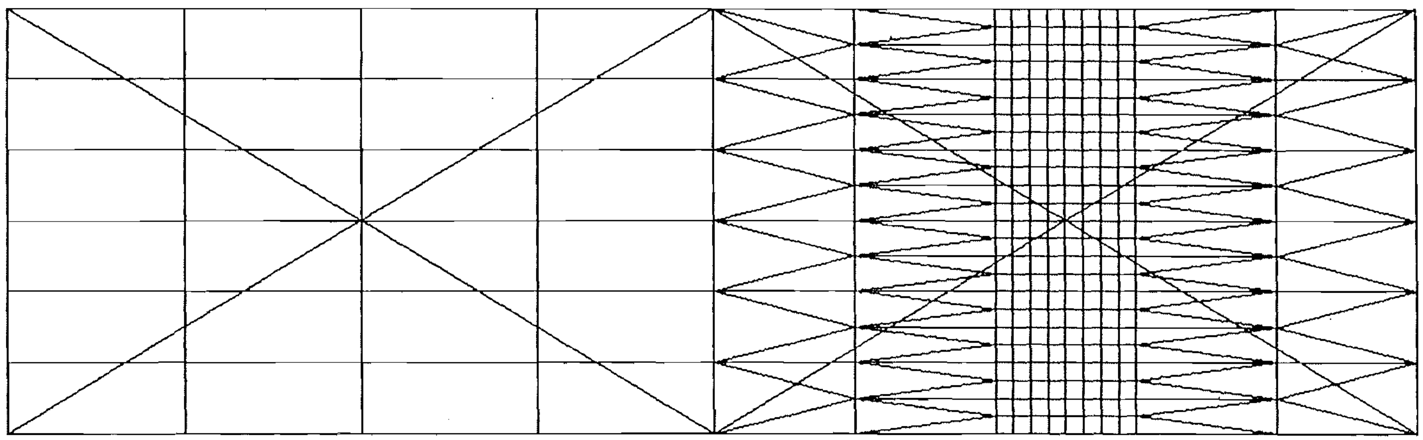
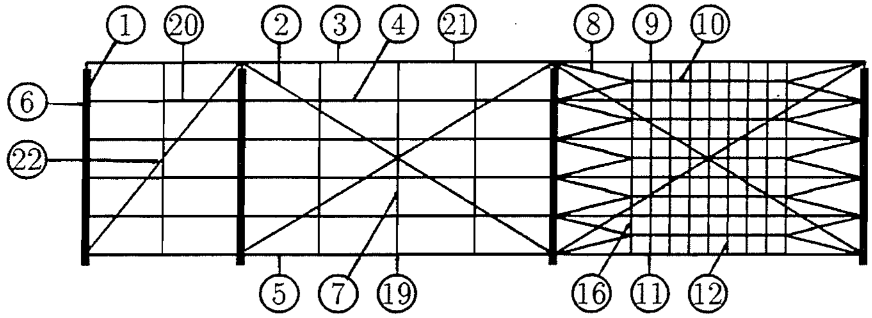
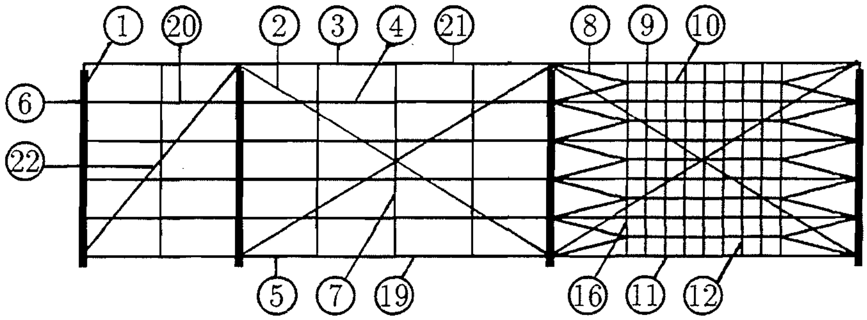


Figure I-8: Model C - 24 ft Fence



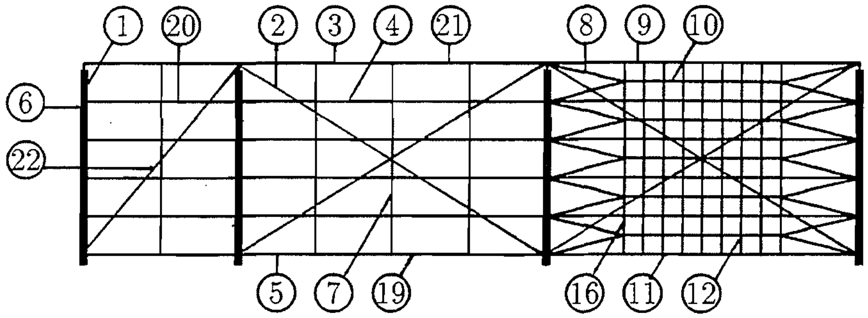
Region	Type	Name	Width (ft.)	Area (sq.in.)	Weight (lb./ft.)
Support	1	Post	.0	2.230	4.810
	2	Stay	.0	.077	.173
Basic Grid	3	Mesh Top Edge	1.0	.040	.290
	4	Mesh Interior Horizontal	2.0	.080	.580
	5	Mesh Bottom Edge	1.0	.040	.290
	6	Mesh Vertical Edge	2.0	.080	.580
	7	Mesh Interior Vertical	4.0	.160	1.160
	8	Mesh Diagonal Transition	1.0	.040	.000
Contact Grid	9	Mesh Top Edge	.5	.020	.145
	10	Mesh Interior Horizontal	1.0	.040	.290
	11	Mesh Bottom Edge	.5	.020	.145
	12	Mesh Interior Vertical	1.0	.040	.290
Transition	13	Mesh Top Edge	.0	.000	.000
	14	Mesh Interior Horizontal	.0	.000	.000
	15	Mesh Bottom Edge	.0	.000	.000
	16	Mesh First Vertical Transition	2.5	.100	.725
	17	Mesh Second Vertical Transition	.0	.000	.000
	18	Mesh Third Vertical Transition	.0	.000	.000
Support	19	Cable Exter. Horizontal	.0	.150	.339
	20	Cable Interior Horizontal	.0	.049	.110
	21	Cable Prestressed Exterior	.0	.150	.339
	22	Prestressed Stay	.0	.150	.339

Figure I-9: Member Properties for Model A.S



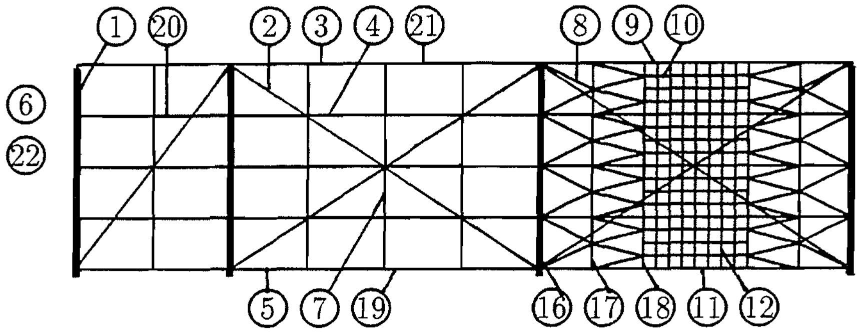
Region	Type	Name	Width (ft.)	Area (sq.in.)	Weight (lb./ft.)
Support	1	Post	.0	2.230	4.810
	2	Stay	.0	.077	.173
Basic Grid	3	Mesh Top Edge	1.0	.080	.580
	4	Mesh Interior Horizontal	2.0	.160	1.160
	5	Mesh Bottom Edge	1.0	.080	.580
	6	Mesh Vertical Edge	2.0	.160	1.160
	7	Mesh Interior Vertical	4.0	.320	2.320
	8	Mesh Diagonal Transition	1.0	.080	.000
Contact Grid	9	Mesh Top Edge	.5	.040	.290
	10	Mesh Interior Horizontal	1.0	.080	.580
	11	Mesh Bottom Edge	.5	.040	.290
	12	Mesh Interior Vertical	1.0	.080	.580
Transition	13	Mesh Top Edge	.0	.000	.000
	14	Mesh Interior Horizontal	.0	.000	.000
	15	Mesh Bottom Edge	.0	.000	.000
	16	Mesh First Vertical Transition	2.5	.200	1.450
	17	Mesh Second Vertical Transition	.0	.000	.000
	18	Mesh Third Vertical Transition	.0	.000	.000
Support	19	Cable Exter. Horizontal	.0	.150	.339
	20	Cable Interior Horizontal	.0	.049	.110
	21	Cable Prestressed Exterior	.0	.150	.339
	22	Prestressed Stay	.0	.150	.339

Figure I-10: Member Properties for Model A.D



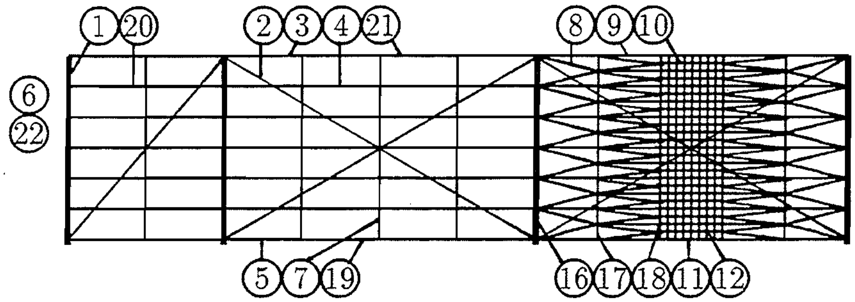
Region	Type	Name	Width (ft.)	Area (sq.in.)	Weight (lb./ft.)
Support	1	Post	.0	2.230	4.810
	2	Stay	.0	.077	.173
Basic Grid	3	Mesh Top Edge	1.0	.120	.870
	4	Mesh Interior Horizontal	2.0	.240	1.740
	5	Mesh Bottom Edge	1.0	.120	.870
	6	Mesh Vertical Edge	2.0	.240	1.740
	7	Mesh Interior Vertical	4.0	.480	3.480
	8	Mesh Diagonal Transition	1.0	.120	.000
Contact Grid	9	Mesh Top Edge	.5	.060	.435
	10	Mesh Interior Horizontal	1.0	.120	.870
	11	Mesh Bottom Edge	.5	.060	.435
	12	Mesh Interior Vertical	1.0	.120	.870
Transition	13	Mesh Top Edge	.0	.000	.000
	14	Mesh Interior Horizontal	.0	.000	.000
	15	Mesh Bottom Edge	.0	.000	.000
	16	Mesh First Vertical Transition	2.5	.300	2.175
	17	Mesh Second Vertical Transition	.0	.000	.000
	18	Mesh Third Vertical Transition	.0	.000	.000
Support	19	Cable Exter. Horizontal	.0	.150	.339
	20	Cable Interior Horizontal	.0	.049	.110
	21	Cable Prestressed Exterior	.0	.150	.339
	22	Prestressed Stay	.0	.150	.339

Figure I-11: Member Properties for Model A.T



Region	Type	Name	Width (ft.)	Area (sq.in.)	Weight (lb./ft.)
Support	1	Post	.0	2.230	4.180
	2	Stay	.0	.077	.173
Basic Grid	3	Mesh Top Edge	2.0	.080	.580
	4	Mesh Interior Horizontal	4.0	.160	1.160
	5	Mesh Bottom Edge	2.0	.080	.580
	6	Mesh Vertical Edge	3.0	.120	.870
	7	Mesh Interior Vertical	6.0	.240	1.740
	8	Mesh Diagonal Transition	2.0	.080	.000
Contact Grid	9	Mesh Top Edge	.5	.020	.145
	10	Mesh Interior Horizontal	1.0	.040	.290
	11	Mesh Bottom Edge	.5	.020	.145
	12	Mesh Interior Vertical	1.0	.040	.290
Transition	13	Mesh Top Edge	1.0	.040	.290
	14	Mesh Interior Horizontal	2.0	.080	.580
	15	Mesh Bottom Edge	1.0	.040	.290
	16	Mesh First Vertical Transition	4.5	.180	1.305
	17	Mesh Second Vertical Transition	3.0	.120	.870
	18	Mesh Third Vertical Transition	2.0	.080	.580
Support	19	Cable Exter. Horizontal	.0	.150	.339
	20	Cable Interior Horizontal	.0	.049	.110
	21	Cable Prestressed Exterior	.0	.150	.339
	22	Prestressed Stay	.0	.150	.339

Figure I-12: Member Properties for Model B

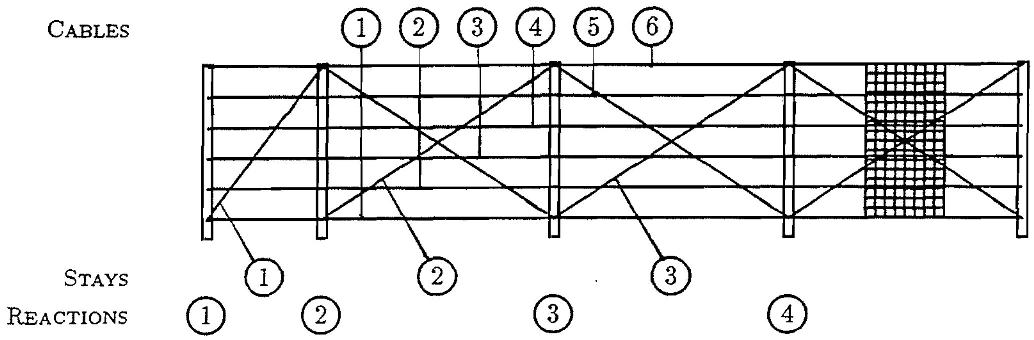


Region	Type	Name	Width (ft.)	Area (sq.in.)	Weight (lb./ft.)
Support	1	Post	.0	2.230	3.960
	2	Stay	.0	.077	.173
Basic Grid	3	Mesh Top Edge	2.0	.080	.580
	4	Mesh Interior Horizontal	4.0	.160	1.160
	5	Mesh Bottom Edge	2.0	.080	.580
	6	Mesh Vertical Edge	5.0	.200	1.450
	7	Mesh Interior Vertical	10.0	.400	2.900
	8	Mesh Diagonal Transition	2.0	.080	.000
Contact Grid	9	Mesh Top Edge	.5	.020	.145
	10	Mesh Interior Horizontal	1.0	.040	.290
	11	Mesh Bottom Edge	.5	.020	.145
	12	Mesh Interior Vertical	1.0	.040	.290
Transition	13	Mesh Top Edge	1.0	.040	.290
	14	Mesh Interior Horizontal	2.0	.080	.580
	15	Mesh Bottom Edge	1.0	.040	.290
	16	Mesh First Vertical Transition	7.5	.300	2.175
	17	Mesh Second Vertical Transition	5.0	.200	1.450
	18	Mesh Third Vertical Transition	3.0	.120	.870
Support	19	Cable Exter. Horizontal	.0	.150	.339
	20	Cable Interior Horizontal	.0	.049	.110
	21	Cable Prestressed Exterior	.0	.150	.339
	22	Prestressed Stay	.0	.150	.339

Figure I-13 Member Properties for Model C

Appendix II

Peak Forces in Components



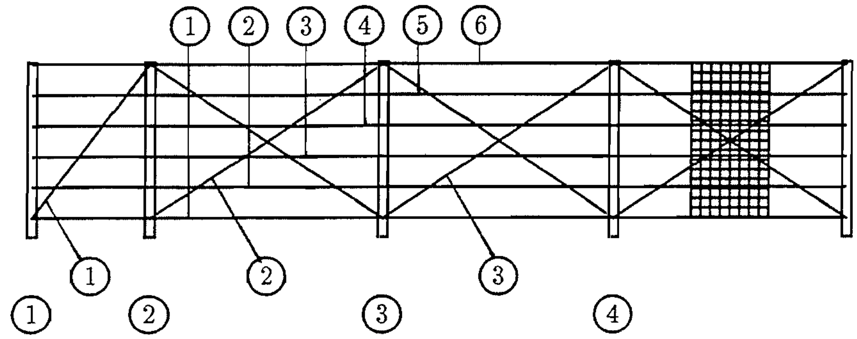
2,000 lbs. 40,000 ft-lbs.

Force	Time (sec.)	X (lbs.)	Y (lbs.)	Z (lbs.)	Mag. (lbs.)
ROCK FORCE	0.75	26.	26726.	-7975.	27890.
STAYS 1	0.51				9553.
2	0.63				3572.
3	0.61				5306.
MESH	0.63				1416.
CABLES 1	0.64				21450.
2	0.00				22.
3	0.04				1185.
4	0.04				991.
5	0.00				0.
6	0.65				11513.
REACTIONS 1	0.67	25552.	1224.	8907.	27087.
2	0.52	1924.	-4183.	-5083.	6857.
3	0.60	4485.	501.	1251.	4683.
4	0.14	-15.	-2282.	-98.	2283.

4,000 lbs. 40,000 ft-lbs.

Force	Time (sec.)	X (lbs.)	Y (lbs.)	Z (lbs.)	Mag. (lbs.)
ROCK FORCE	0.78	-13.	27392.	-11764.	29810.
STAYS 1	0.92				10343.
2	0.90				4975.
3	0.96				6758.
MESH	0.92				2151.
CABLES 1	1.00				23888.
2	0.00				3.
3	0.05				839.
4	0.05				801.
5	0.00				0.
6	0.94				16010.
REACTIONS 1	0.95	29861.	11.	11976.	32173.
2	0.66	1718.	-4077.	-5467.	7032.
3	0.96	5716.	467.	916.	5807.
4	0.18	-8.	-1691.	-53.	1691.

Figure II-1: Peak Forces - Model A.S
40,000 ft-lb Rockfalls



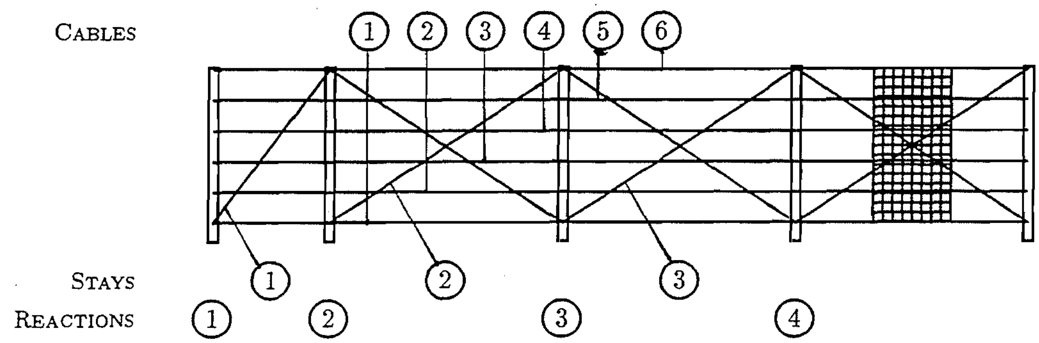
2,000 lbs. 80,000 ft-lbs.

Force	Time (sec.)	X (lbs.)	Y (lbs.)	Z (lbs.)	Mag. (lbs.)
ROCK FORCE	0.64	-29.	40608.	-10700.	41993.
STAYS 1	0.55				14199.
2	0.49				6268.
3	0.45				8589.
MESH	0.49				3000.
CABLES 1	0.48				36643.
2	0.00				0.
3	0.02				1103.
4	0.02				1048.
5	0.00				0.
6	0.51				19619.
REACTIONS 1	0.53	43711.	-490.	18661.	47529.
2	0.23	2163.	-9825.	-855.	10096.
3	0.45	7272.	747.	1784.	7525.
4	0.11	-25.	-2994.	-200.	3001.

4,000 lbs. 80,000 ft-lbs.

Force	Time (sec.)	X (lbs.)	Y (lbs.)	Z (lbs.)	Mag. (lbs.)
ROCK FORCE	0.74	-19.	39531.	-29127.	49102.
STAYS 1	0.67				13343.
2	0.70				6560.
3	0.73				9234.
MESH	0.69				3769.
CABLES 1	0.72				37686.
2	0.00				22.
3	0.03				1096.
4	0.03				993.
5	0.00				0.
6	0.70				21286.
REACTIONS 1	0.71	45706.	-1607.	18725.	49419.
2	0.74	5313.	1341.	-7659.	9417.
3	0.72	7800.	535.	1207.	7911.
4	0.15	-14.	-2275.	-163.	2280.

Figure II-2: Peak Forces - Model A.S
80,000 ft-lb Rockfalls



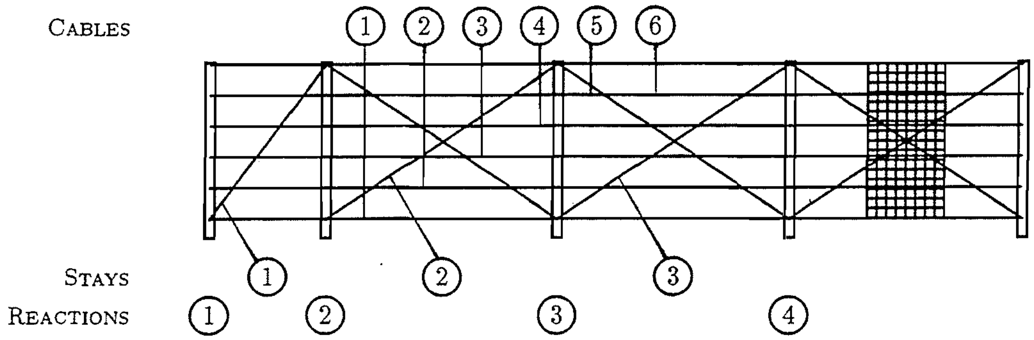
2,000 lbs. 40,000 ft-lbs.

Force	Time (sec.)	X (lbs.)	Y (lbs.)	Z (lbs.)	Mag. (lbs.)
ROCK FORCE	0.78	0.	27399.	-5997.	28047.
STAYS 1	0.91				10414.
2	0.88				4065.
3	0.58				5260.
MESH	0.57				1675.
CABLES 1	0.64				21914.
2	0.00				23.
3	0.03				1079.
4	0.03				1141.
5	0.00				0.
6	0.55				12176.
REACTIONS 1	0.59	26216.	4033.	9354.	28125.
2	0.30	1625.	-7748.	-839.	7961.
3	0.58	4460.	597.	1331.	4692.
4	0.14	-21.	-2778.	-152.	2782.

4,000 lbs. 40,000 ft-lbs.

Force	Time (sec.)	X (lbs.)	Y (lbs.)	Z (lbs.)	Mag. (lbs.)
ROCK FORCE	0.81	9.	26786.	-12574.	29590.
STAYS 1	0.95				11318.
2	0.94				5393.
3	0.85				6073.
MESH	0.92				2193.
CABLES 1	0.95				24686.
2	0.00				0.
3	0.05				1049.
4	0.04				924.
5	0.00				0.
6	0.93				15969.
REACTIONS 1	0.94	31776.	-382.	13485.	34520.
2	0.95	4427.	504.	-6037.	7502.
3	0.85	5139.	421.	887.	5231.
4	0.19	-13.	-2169.	-129.	2173.

Figure II-3: Peak Forces - Model A.D
40,000 ft-lb Rockfalls



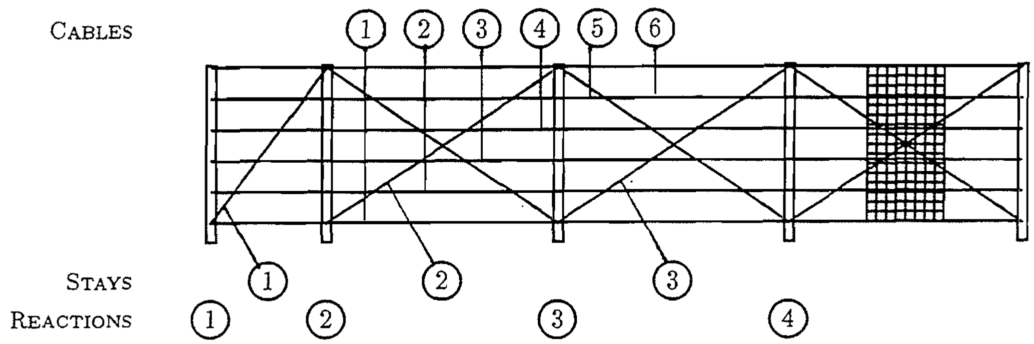
2,000 lbs. 80,000 ft-lbs.

Force	Time (sec.)	X (lbs.)	Y (lbs.)	Z (lbs.)	Mag. (lbs.)
ROCK FORCE	0.66	4.	40038.	-7501.	40734.
STAYS 1	0.24				15911.
2	0.52				6437.
3	0.44				9445.
MESH	0.44				3237.
CABLES 1	0.49				38339.
2	0.00				0.
3	0.03				1376.
4	0.03				1359.
5	0.00				0.
6	0.44				19211.
REACTIONS 1	0.49	44470.	3055.	17336.	47827.
2	0.24	2594.	-11820.	-1397.	12181.
3	0.44	8012.	1070.	2685.	8517.
4	0.11	-39.	-3902.	-302.	3913.

4,000 lbs. 80,000 ft-lbs.

Force	Time (sec.)	X (lbs.)	Y (lbs.)	Z (lbs.)	Mag. (lbs.)
ROCK FORCE	0.76	-16.	40885.	-26981.	48985.
STAYS 1	0.76				14438.
2	0.66				7147.
3	0.59				9840.
MESH	0.67				3790.
CABLES 1	0.65				40963.
2	0.00				23.
3	0.04				1139.
4	0.03				1179.
5	0.00				0.
6	0.71				22265.
REACTIONS 1	0.67	48778.	-180.	20194.	52792.
2	0.80	4820.	1793.	-8650.	10063.
3	0.59	8333.	745.	2116.	8629.
4	0.14	-23.	-2917.	-172.	2922.

Figure II-4: Peak Forces - Model A.D
80,000 ft-lb Rockfalls



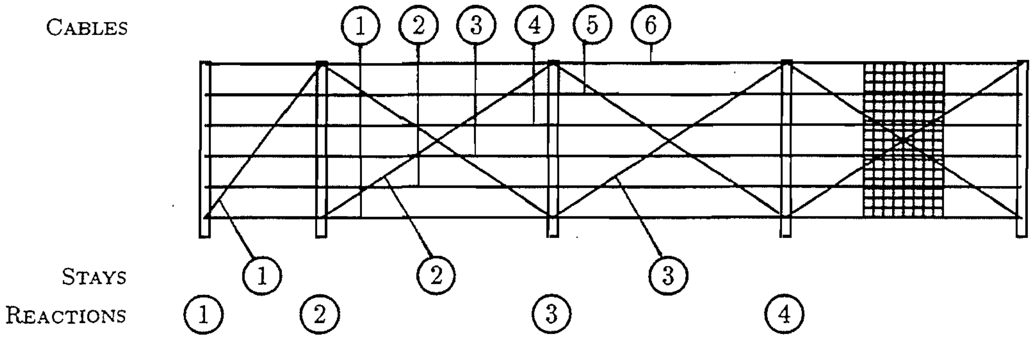
2,000 lbs. 40,000 ft-lbs.

Force	Time (sec.)	X (lbs.)	Y (lbs.)	Z (lbs.)	Mag. (lbs.)
ROCK FORCE	0.82	-10.	27774.	-4055.	28067.
STAYS 1	0.31				11604.
2	0.21				4185.
3	0.60				5274.
MESH	0.58				1803.
CABLES 1	0.65				21884.
2	0.00				22.
3	0.04				1289.
4	0.04				1155.
5	0.00				0.
6	0.93				12443.
REACTIONS 1	0.61	26748.	4464.	9623.	28774.
2	0.31	1866.	-8674.	-1048.	8934.
3	0.61	4460.	616.	1306.	4687.
4	0.14	-26.	-3190.	-180.	3195.

4,000 lbs. 40,000 ft-lbs.

Force	Time (sec.)	X (lbs.)	Y (lbs.)	Z (lbs.)	Mag. (lbs.)
ROCK FORCE	0.83	12.	25244.	-12221.	28046.
STAYS 1	1.03				12241.
2	0.99				5676.
3	0.83				6010.
MESH	0.95				2260.
CABLES 1	0.98				24041.
2	0.00				0.
3	0.04				954.
4	0.03				931.
5	0.00				0.
6	0.96				15723.
REACTIONS 1	0.99	31816.	-601.	14338.	34902.
2	1.07	3340.	432.	-7600.	8312.
3	0.82	5074.	478.	1678.	5365.
4	0.19	-17.	-2525.	-155.	2530.

Figure II-5: Peak Forces - Model A.T
40,000 ft-lb Rockfalls



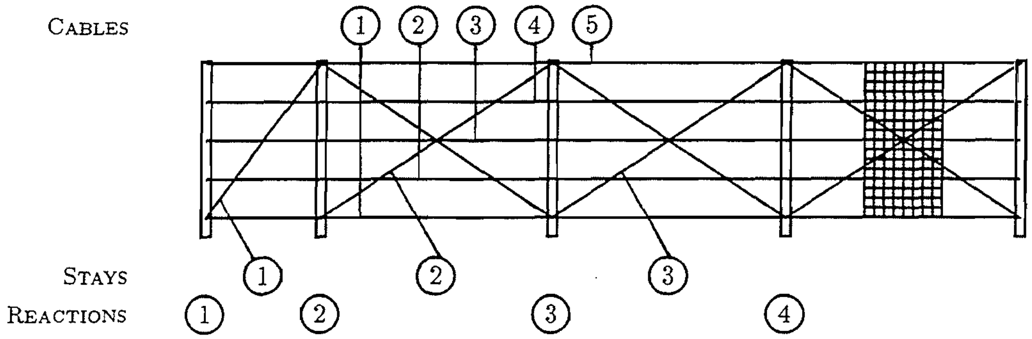
2,000 lbs. 80,000 ft-lbs.

Force	Time (sec.)	X (lbs.)	Y (lbs.)	Z (lbs.)	Mag. (lbs.)
ROCK FORCE	0.69	-13.	38560.	-4577.	38830.
STAYS 1	0.26				17884.
2	0.54				6149.
3	0.45				9107.
MESH	0.45				3240.
CABLES 1	0.49				38194.
2	0.00				0.
3	0.03				1784.
4	0.03				1823.
5	0.00				0.
6	0.46				18507.
REACTIONS 1	0.49	44237.	4145.	17401.	47716.
2	0.25	3005.	-13233.	-1652.	13670.
3	0.45	7727.	1169.	2707.	8270.
4	0.11	-47.	-4355.	-342.	4368.

4,000 lbs. 80,000 ft-lbs.

Force	Time (sec.)	X (lbs.)	Y (lbs.)	Z (lbs.)	Mag. (lbs.)
ROCK FORCE	0.78	24.	40545.	-23257.	46741.
STAYS 1	0.86				15143.
2	0.67				7336.
3	0.59				10089.
MESH	0.65				3729.
CABLES 1	0.66				42144.
2	0.00				22.
3	0.03				1337.
4	0.03				1365.
5	0.00				0.
6	0.67				21183.
REACTIONS 1	0.67	49695.	862.	20581.	53795.
2	0.86	4246.	2534.	-9798.	10974.
3	0.58	8524.	836.	2553.	8937.
4	0.14	-30.	-3417.	-207.	3423.

Figure II-6: Peak Forces - Model A.T
80,000 ft-lb Rockfalls



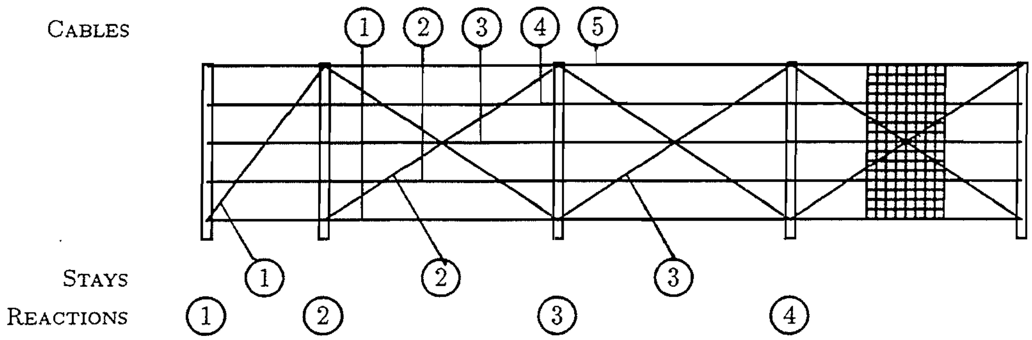
2,000 lbs. 40,000 ft-lbs.

Force	Time (sec.)	X (lbs.)	Y (lbs.)	Z (lbs.)	Mag. (lbs.)
ROCK FORCE	1.28	-10.	21958.	-879.	21975.
STAYS 1	0.43				8610.
2	0.33				3199.
3	0.22				2538.
MESH	0.46				1188.
CABLES 1	0.63				18068.
2	0.00				0.
3	0.03				1431.
4	0.00				0.
5	1.44				6870.
REACTIONS 1	0.49	20051.	8082.	2319.	21742.
2	0.45	837.	-6805.	-463.	6871.
3	0.22	2108.	125.	57.	2112.
4	0.21	-14.	-2340.	-70.	2341.

4,000 lbs. 40,000 ft-lbs.

Force	Time (sec.)	X (lbs.)	Y (lbs.)	Z (lbs.)	Mag. (lbs.)
ROCK FORCE	1.10	10.	30233.	-2587.	30343.
STAYS 1	1.61				8877.
2	1.47				3234.
3	1.37				2713.
MESH	0.62				1105.
CABLES 1	0.78				17015.
2	0.00				0.
3	0.05				1169.
4	0.00				0.
5	1.57				8020.
REACTIONS 1	0.77	19503.	3867.	3968.	20274.
2	1.20	235.	-3933.	-5649.	6887.
3	1.36	2245.	149.	597.	2327.
4	0.29	-10.	-1965.	-76.	1966.

Figure II-7: Peak Forces - Model B
40,000 ft-lb Rockfalls



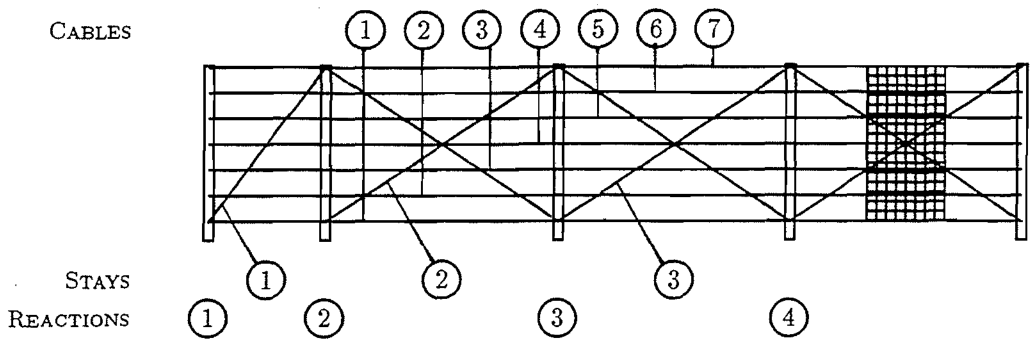
2,000 lbs. 80,000 ft-lbs.

Force	Time (sec.)	X (lbs.)	Y (lbs.)	Z (lbs.)	Mag. (lbs.)
ROCK FORCE	1.07	-62.	37379.	-1228.	37398.
STAYS 1	0.38				12775.
2	1.17				4451.
3	0.75				4928.
MESH	0.41				1758.
CABLES 1	0.50				25838.
2	0.00				0.
3	0.03				1920.
4	0.00				0.
5	1.21				11877.
REACTIONS 1	0.50	30809.	8507.	7780.	32894.
2	0.38	1437.	-10132.	-965.	10278.
3	0.74	4089.	415.	1491.	4371.
4	1.44	-44.	-530.	-4190.	4223.

4,000 lbs. 80,000 ft-lbs.

Force	Time (sec.)	X (lbs.)	Y (lbs.)	Z (lbs.)	Mag. (lbs.)
ROCK FORCE	1.10	-23.	40615.	-14383.	43086.
STAYS 1	1.26				13279.
2	1.22				5427.
3	0.96				5837.
MESH	1.03				2155.
CABLES 1	1.08				25276.
2	0.00				0.
3	0.04				1503.
4	0.00				0.
5	1.22				14447.
REACTIONS 1	1.26	31750.	-3904.	14617.	35170.
2	1.29	3505.	2999.	-8473.	9647.
3	0.94	4830.	284.	1471.	5057.
4	0.21	-16.	-2477.	-81.	2478.

Figure II-8: Peak Forces - Model B
80,000 ft-lb Rockfalls



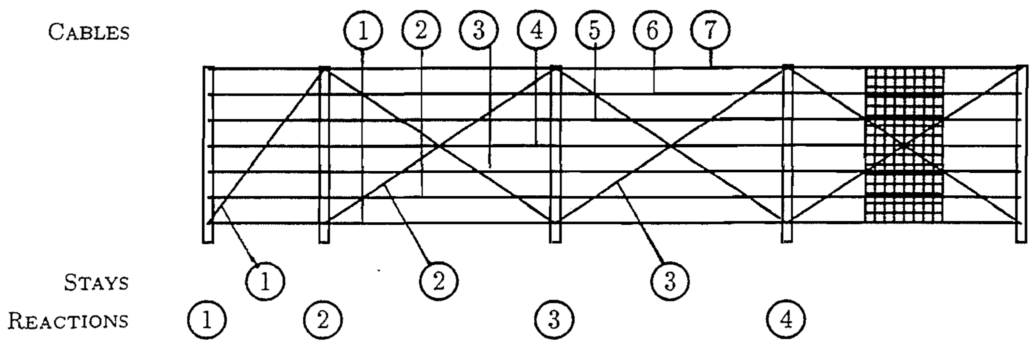
2,000 lbs. 40,000 ft-lbs.

Force	Time (sec.)	X (lbs.)	Y (lbs.)	Z (lbs.)	Mag. (lbs.)
ROCK FORCE	0.83	22.	1270.	-6483.	6606.
STAYS 1	0.69				6743.
2	0.53				2897.
3	0.35				2718.
MESH	0.83				884.
CABLES 1	0.99				12787.
2	0.00				0.
3	0.10				614.
4	0.04				1819.
5	0.11				635.
6	0.00				0.
7	0.45				6150.
REACTIONS 1	0.79	15633.	6395.	1069.	16924.
2	0.77	446.	-5241.	-355.	5271.
3	0.35	2327.	112.	39.	2329.
4	0.34	-16.	-2383.	-52.	2383.

4,000 lbs. 40,000 ft-lbs.

Force	Time (sec.)	X (lbs.)	Y (lbs.)	Z (lbs.)	Mag. (lbs.)
ROCK FORCE	1.45	60.	26601.	-3384.	26815.
STAYS 1	0.81				5697.
2	0.66				2215.
3	0.46				2181.
MESH	0.95				1253.
CABLES 1	1.14				13956.
2	0.00				0.
3	0.14				447.
4	0.05				1403.
5	0.14				399.
6	0.00				0.
7	0.62				5146.
REACTIONS 1	1.13	16469.	4182.	2168.	17129.
2	1.78	-23.	-3976.	-2095.	4494.
3	0.46	1868.	248.	32.	1884.
4	0.46	-10.	-1867.	-53.	1867.

Figure II-9: Peak Forces - Model C



2,000 lbs. 80,000 ft-lbs.

Force	Time (sec.)	X (lbs.)	Y (lbs.)	Z (lbs.)	Mag. (lbs.)
ROCK FORCE	0.49	44.	1279.	-10230.	10309.
STAYS 1	0.63				10723.
2	0.43				4376.
3	0.27				3823.
MESH	0.49				1453.
CABLES 1	0.81				19390.
2	0.00				0.
3	0.08				949.
4	0.03				2041.
5	0.08				898.
6	0.00				0.
7	0.46				8148.
REACTIONS 1	0.67	25293.	10707.	2844.	27612.
2	0.63	1201.	-8360.	-626.	8468.
3	0.27	3271.	36.	75.	3271.
4	0.25	-33.	-3583.	-75.	3584.

4,000 lbs. 80,000 ft-lbs.

Force	Time (sec.)	X (lbs.)	Y (lbs.)	Z (lbs.)	Mag. (lbs.)
ROCK FORCE	1.65	-39.	28719.	-1589.	28762.
STAYS 1	0.74				8769.
2	0.53				3455.
3	0.34				2936.
MESH	0.92				1515.
CABLES 1	0.99				21770.
2	0.00				0.
3	0.11				649.
4	0.03				1586.
5	0.12				646.
6	0.00				0.
7	0.52				6858.
REACTIONS 1	0.88	24727.	7389.	3637.	26062.
2	1.62	-57.	-4292.	-5588.	7046.
3	0.34	2513.	96.	45.	2515.
4	0.34	-19.	-2590.	-78.	2591.

Figure II-10: Peak Forces - Model C

Appendix III

Time Domain Plots

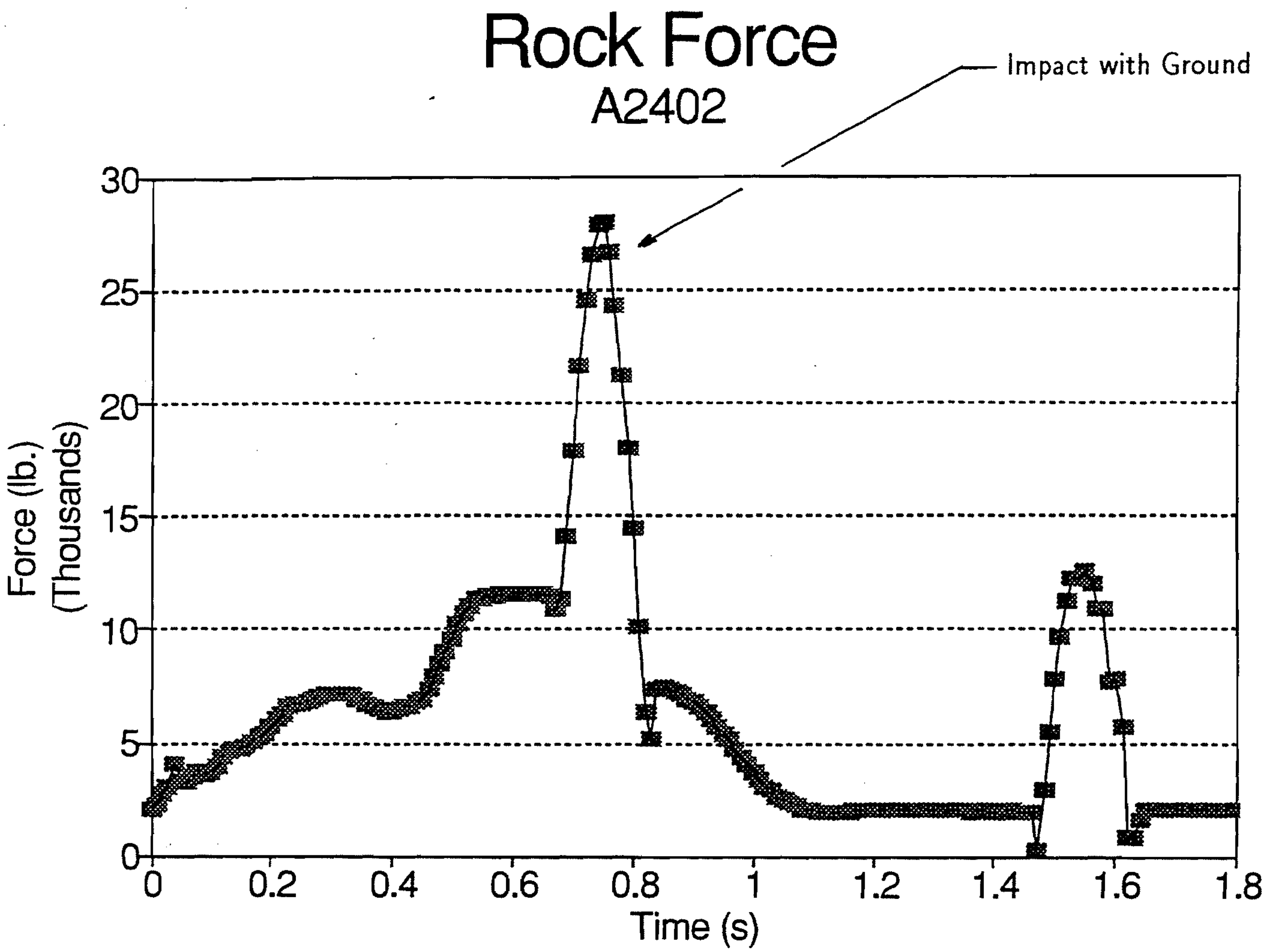


Figure III - 1
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model A.S

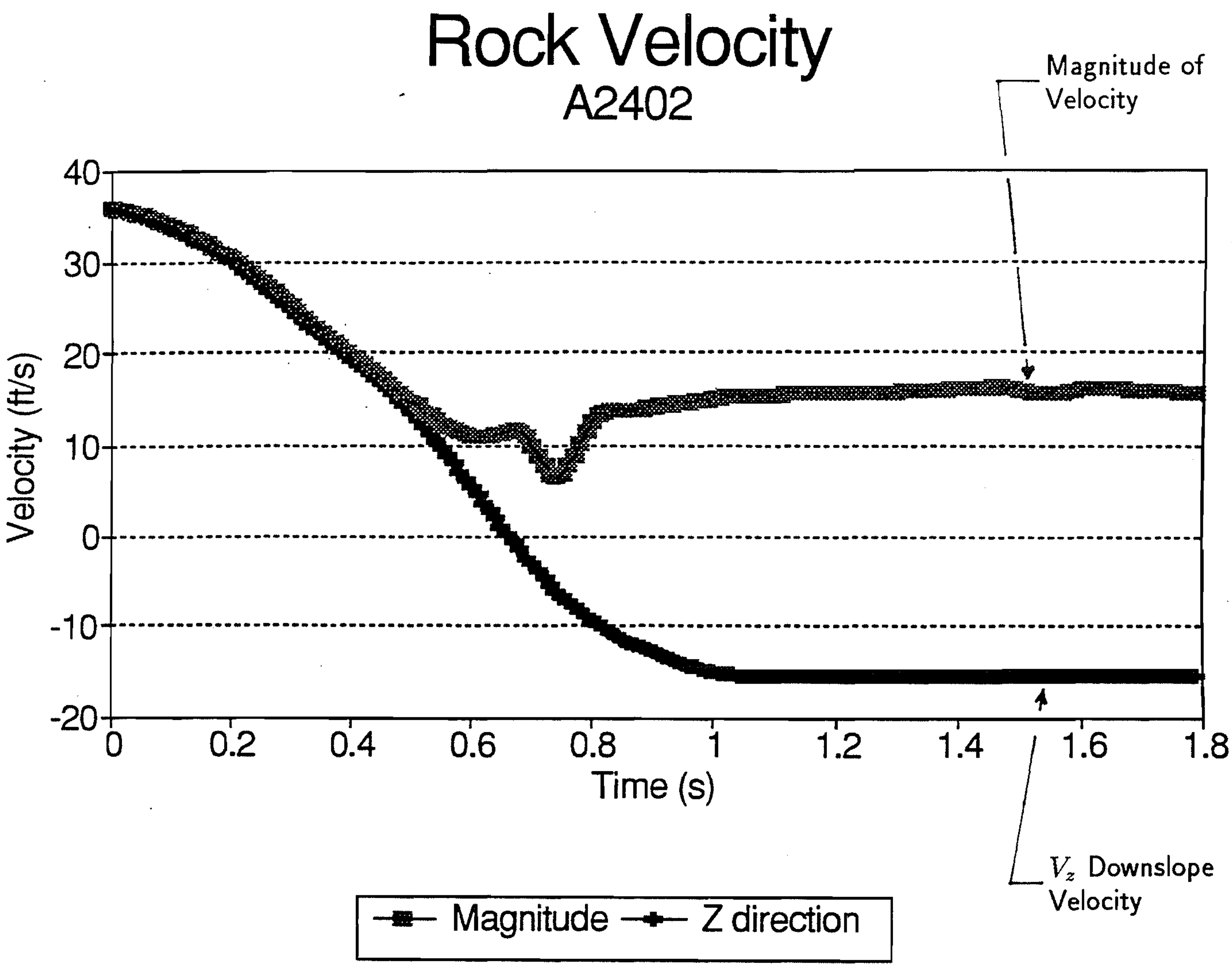


Figure III - 2
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model A.S

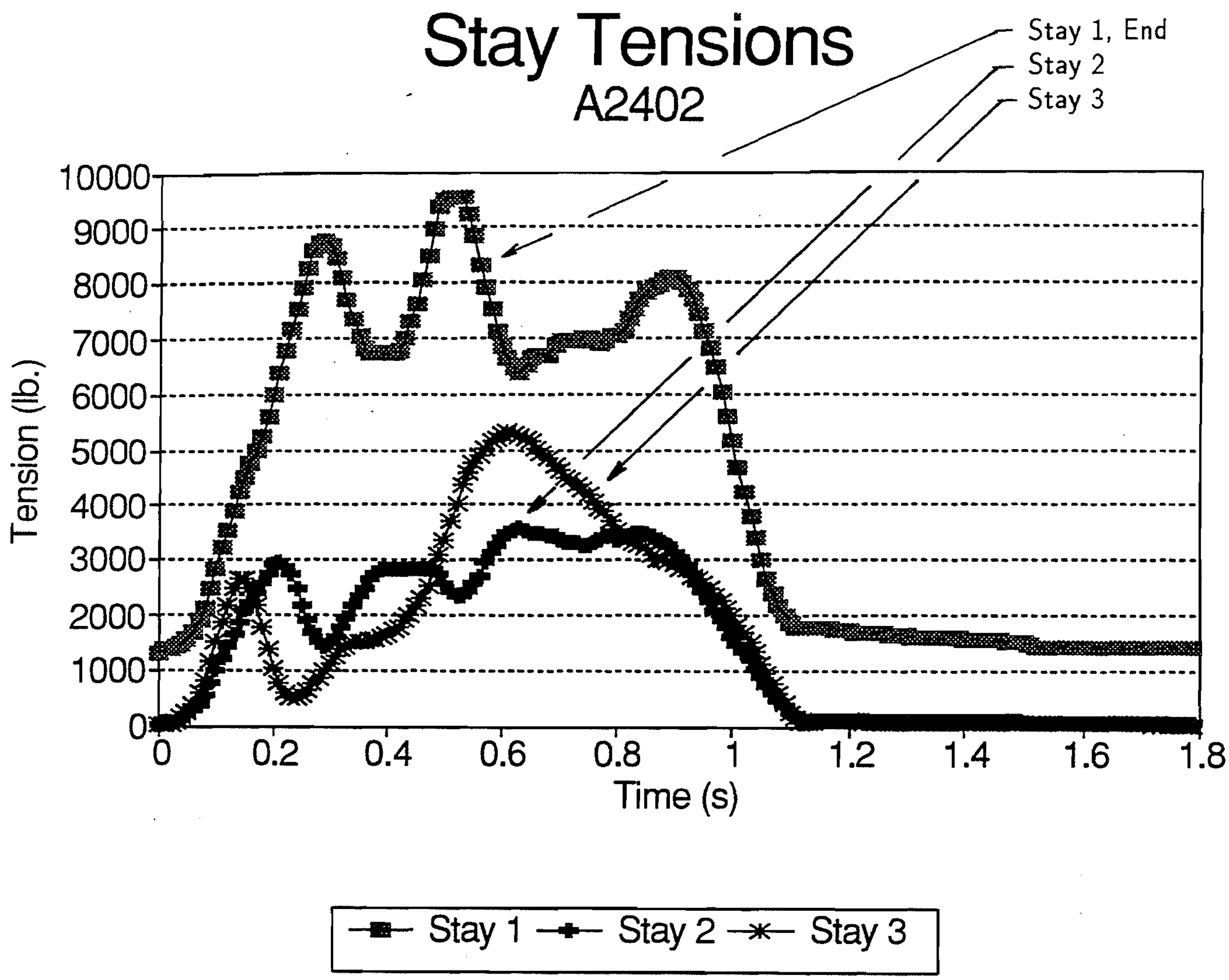


Figure III - 3
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model A.S

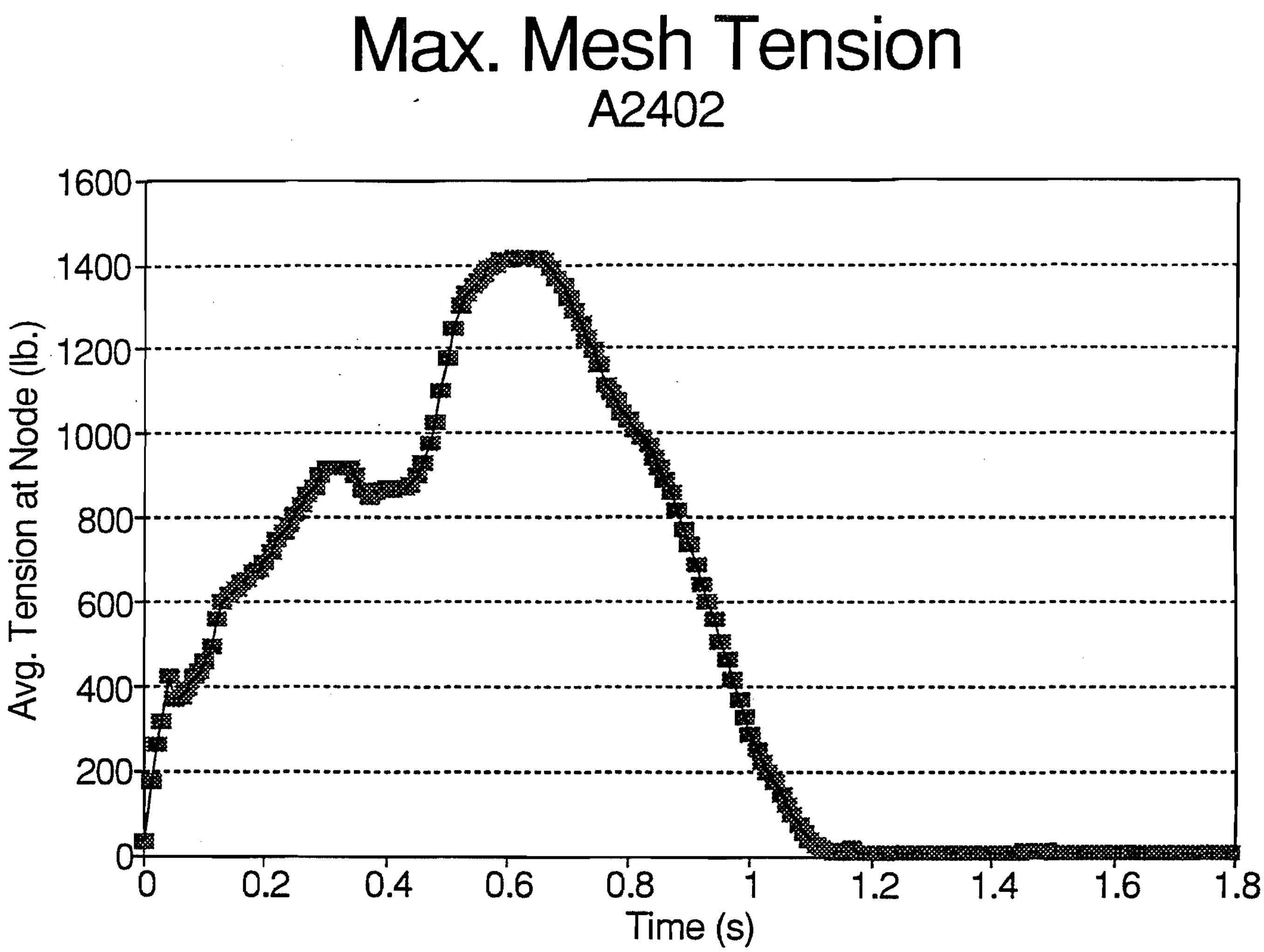


Figure III - 4
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model A.S

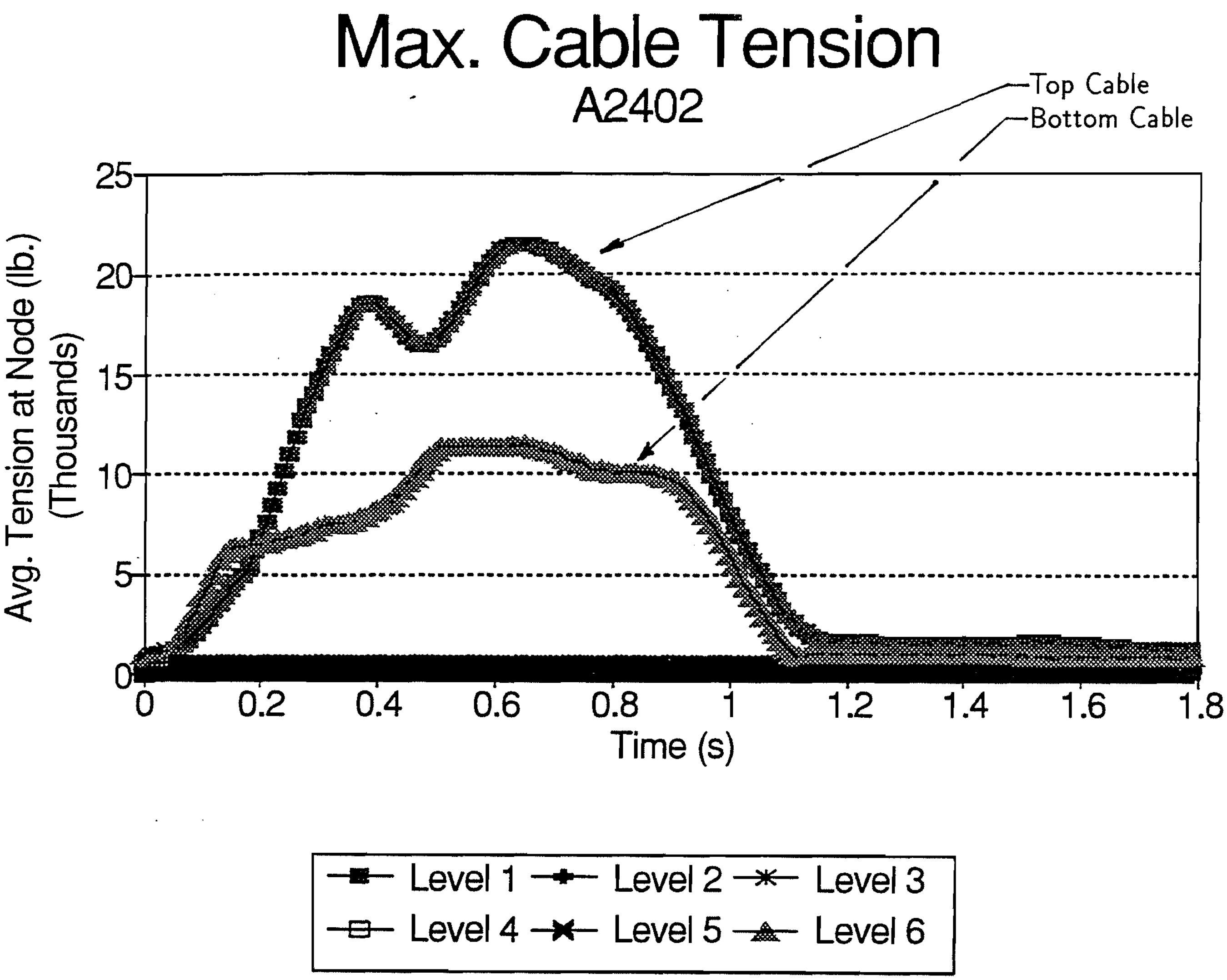
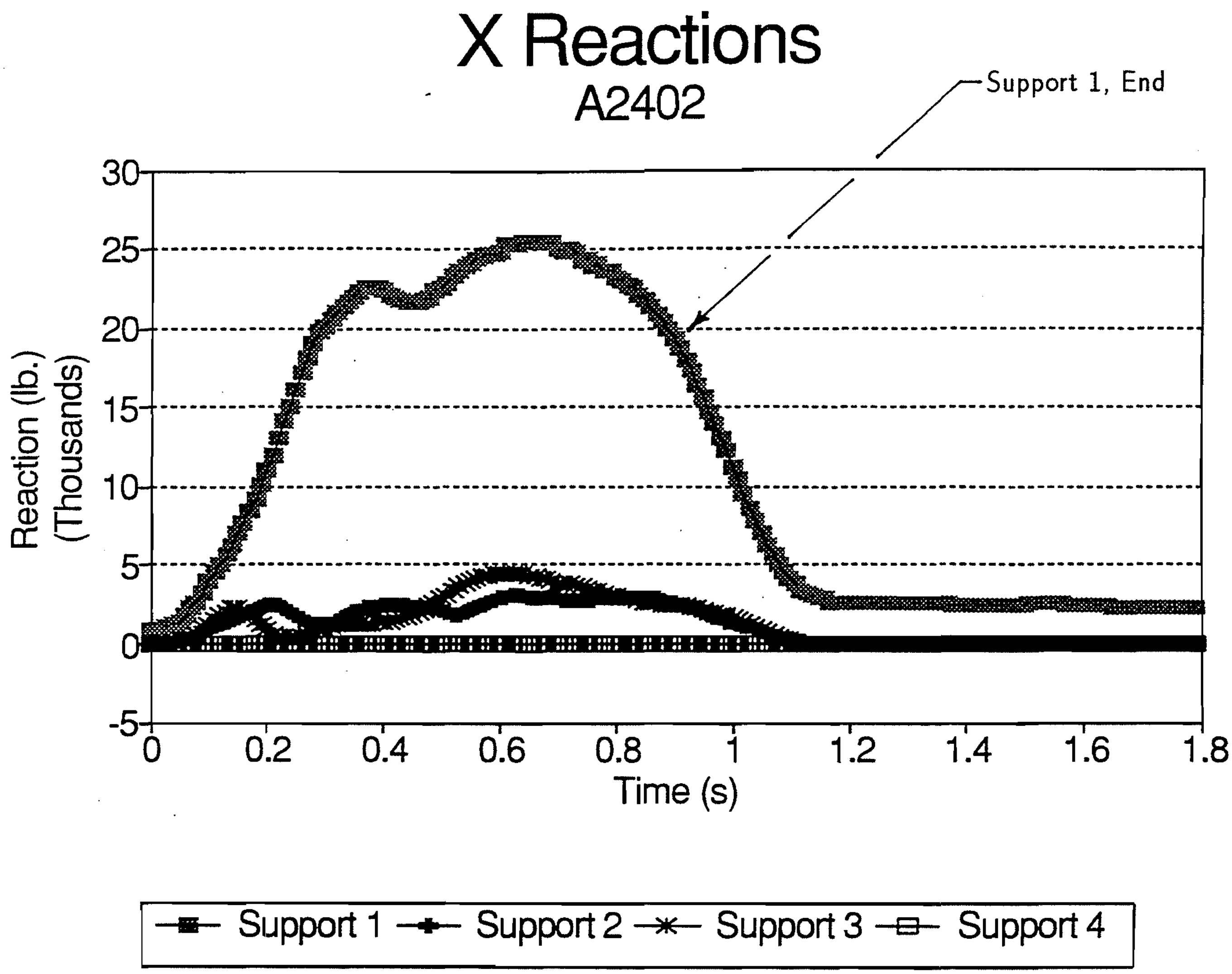
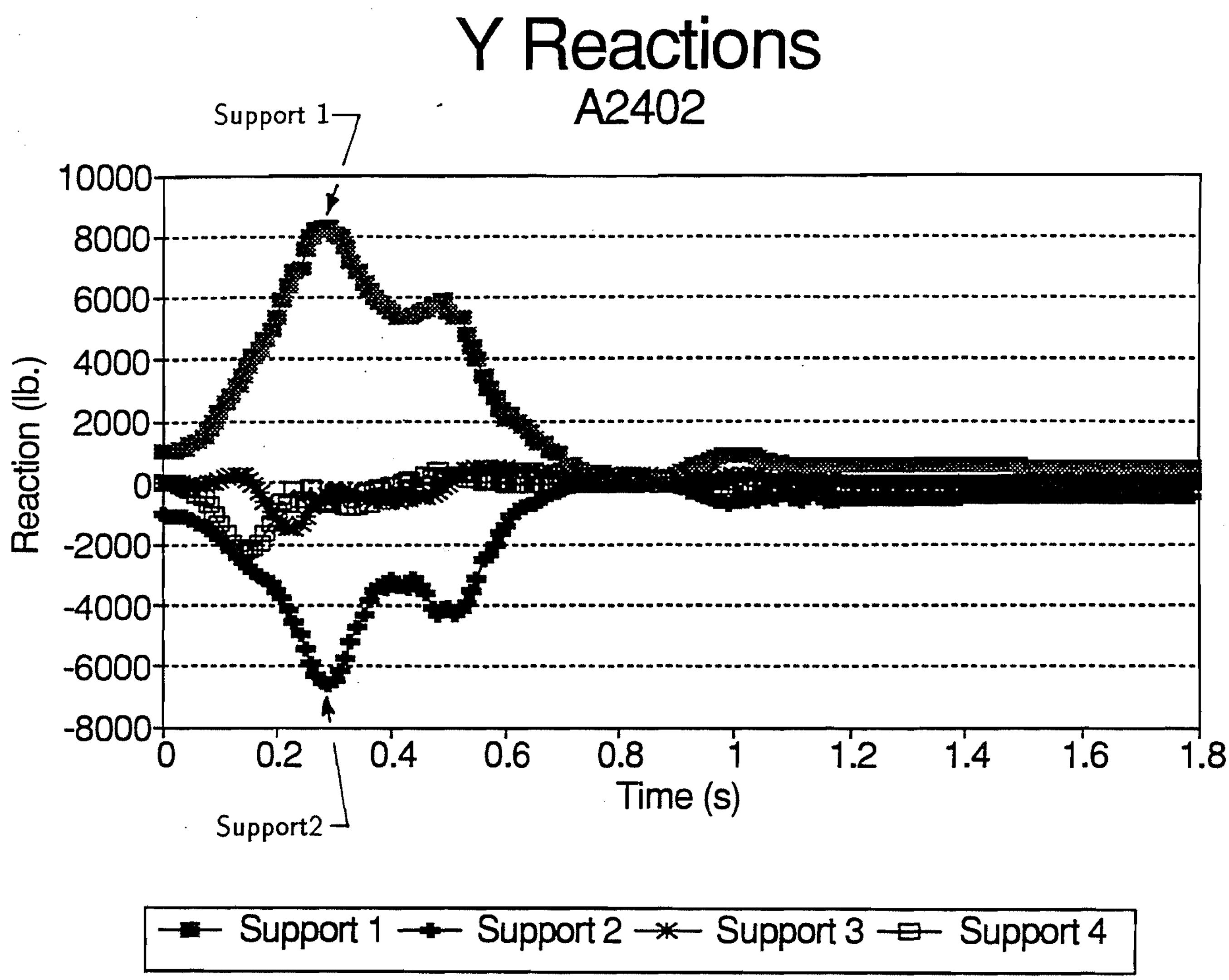


Figure III - 5
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model A.S



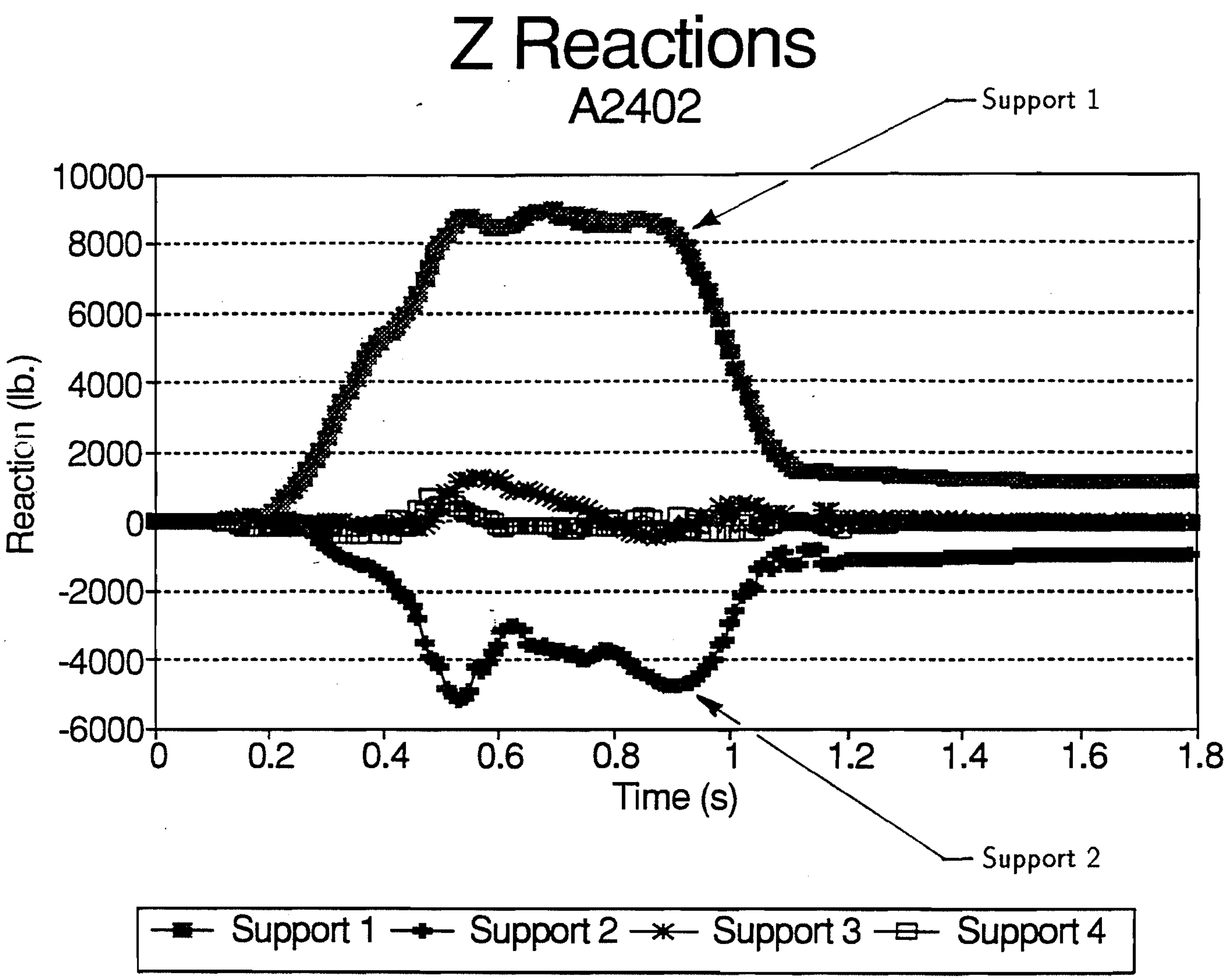
X Reaction, in-plane

Figure III - 6
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model A.S



Y Reaction, Vertical

Figure III - 7
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model A.S



Z Reaction, Downslope

Figure III - 8
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model A.S

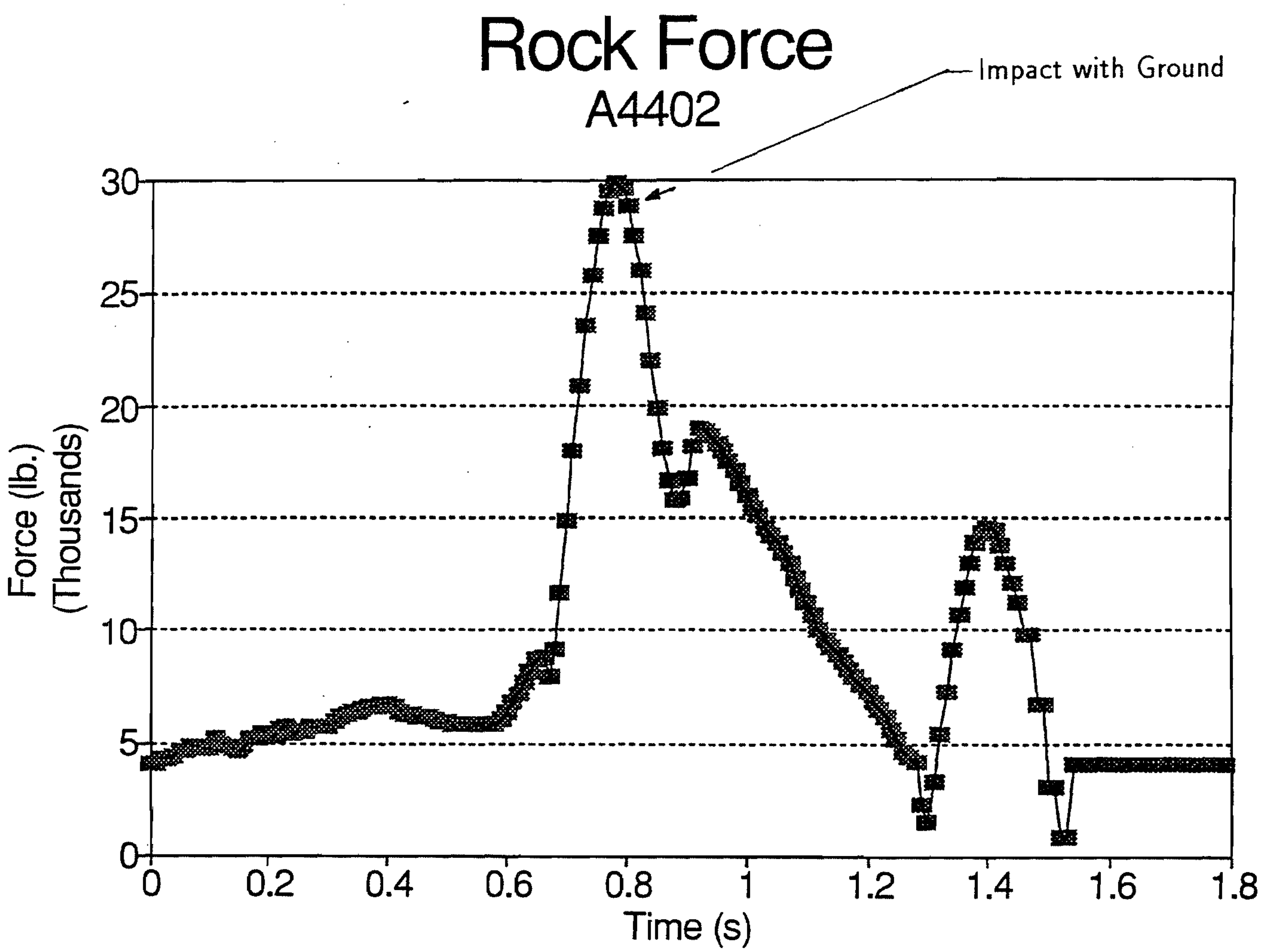


Figure III - 9
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model A.S

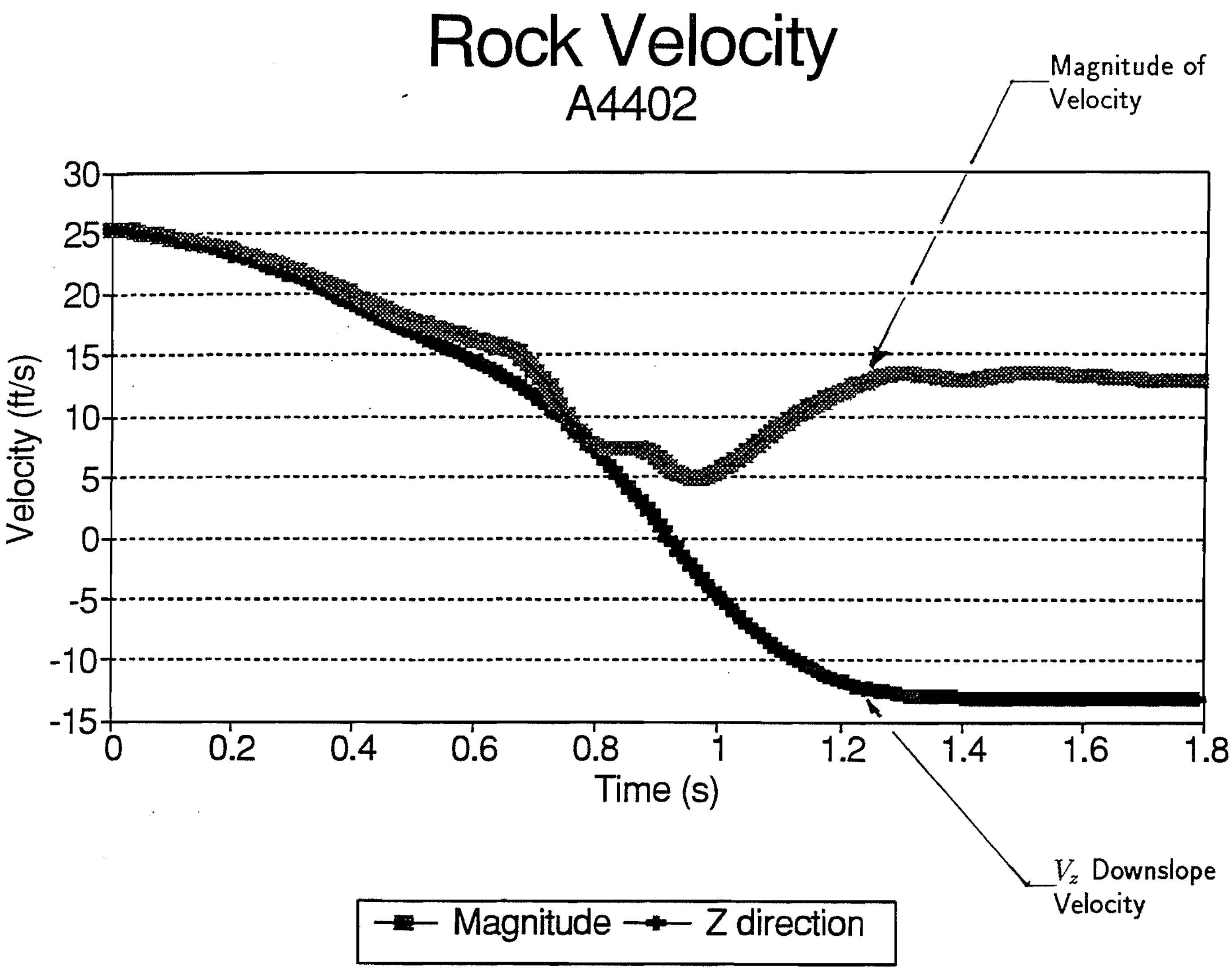


Figure III - 10
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model A.S

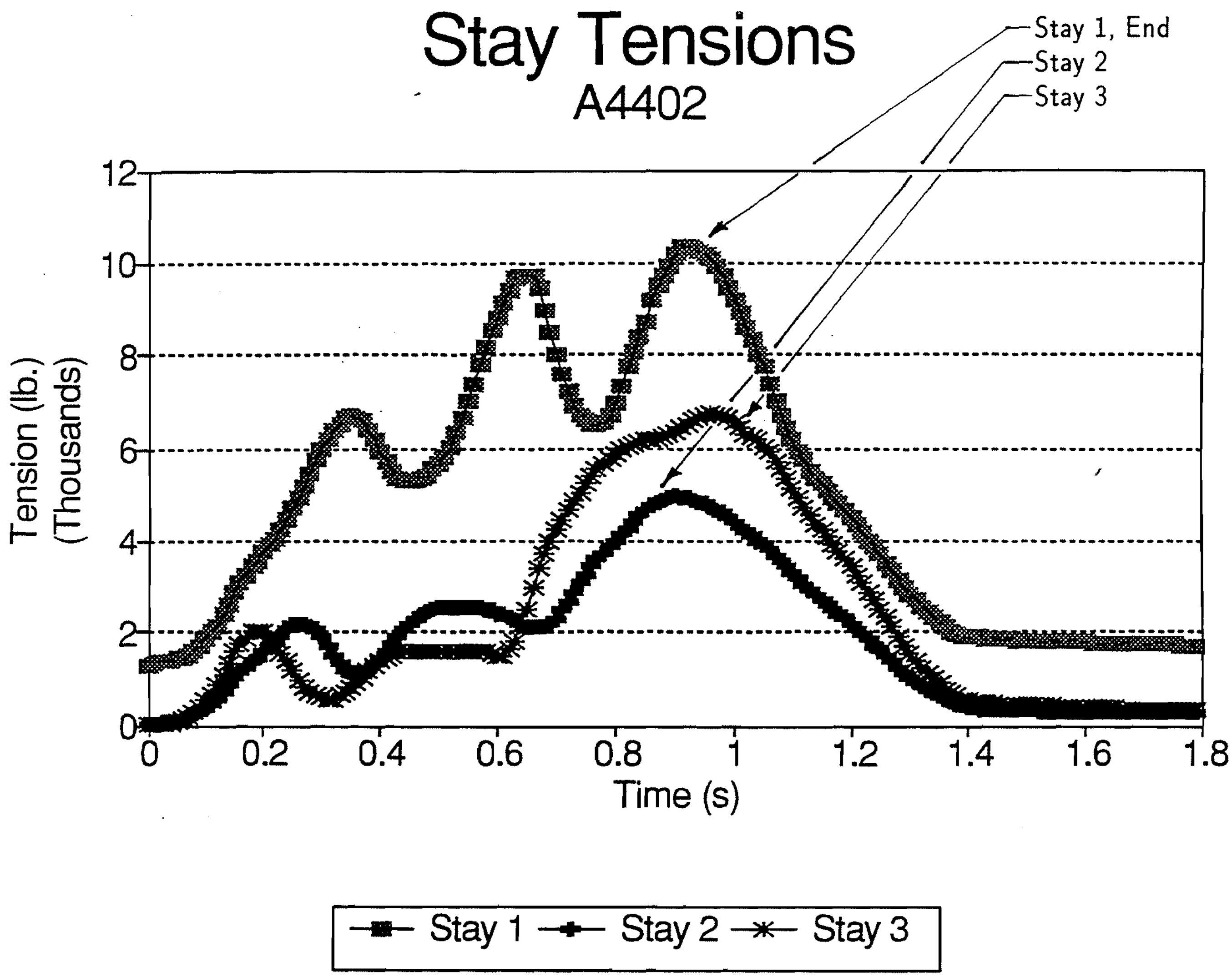


Figure III - 11
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model A.S

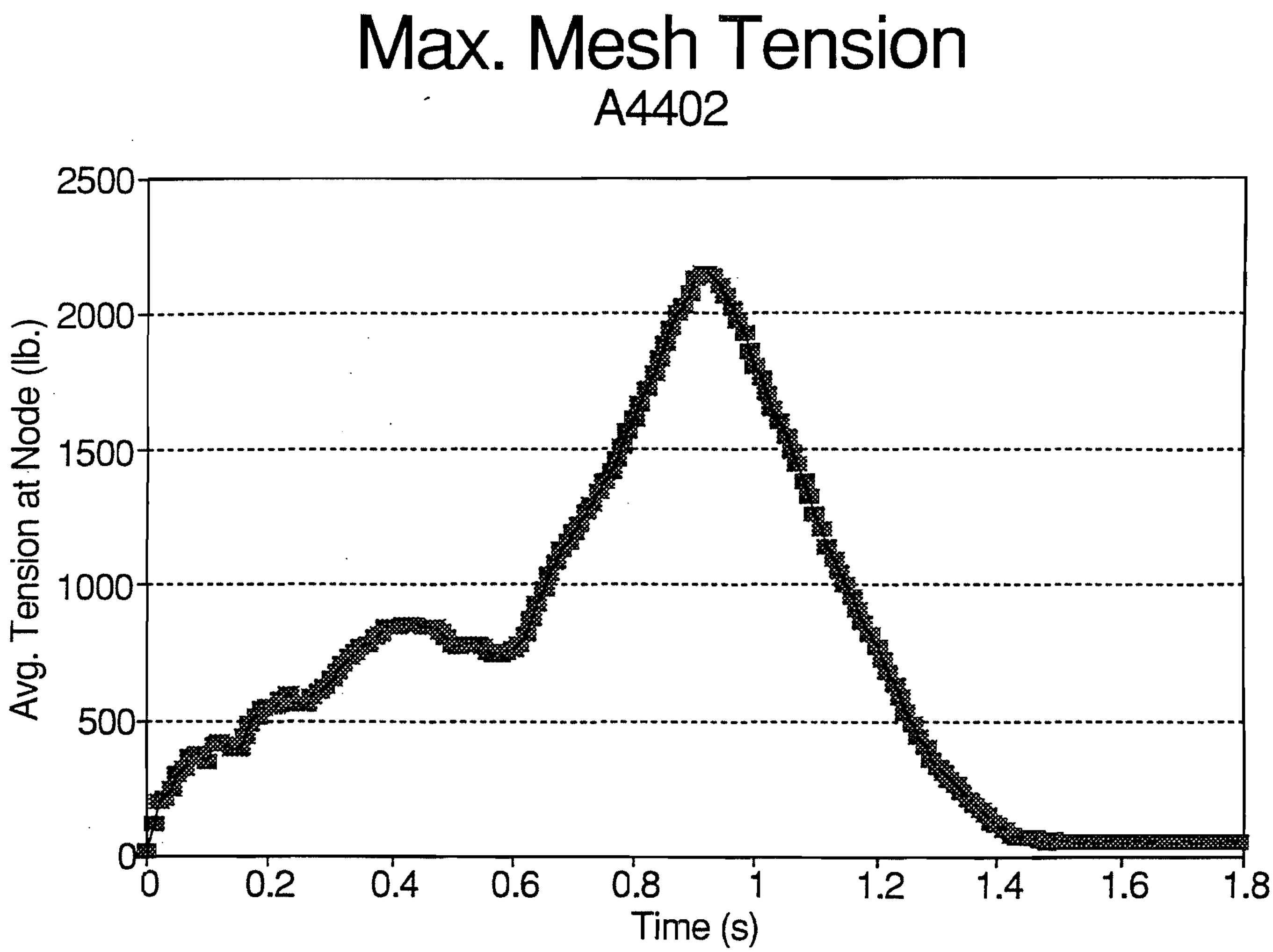


Figure III - 12
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model A.S

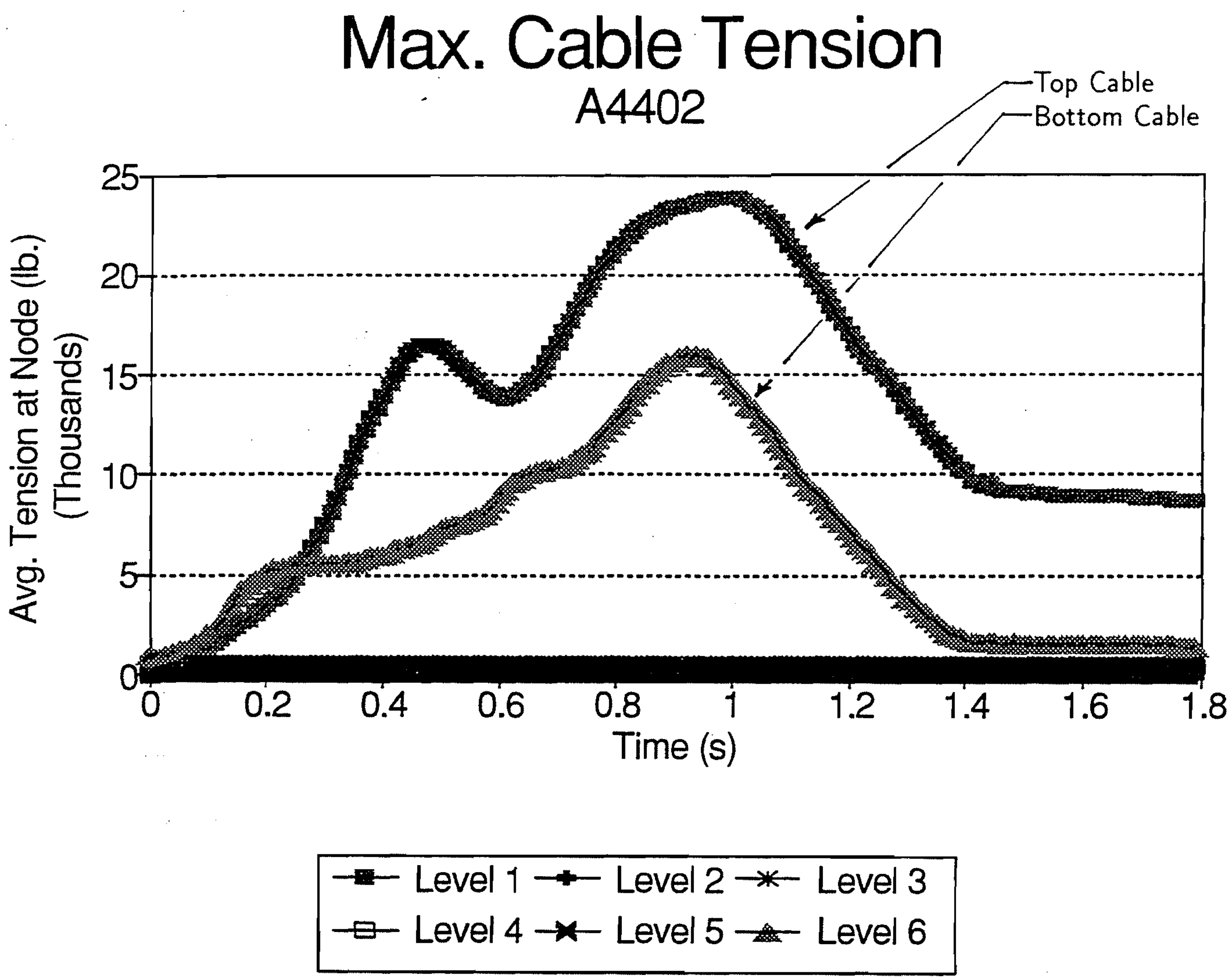
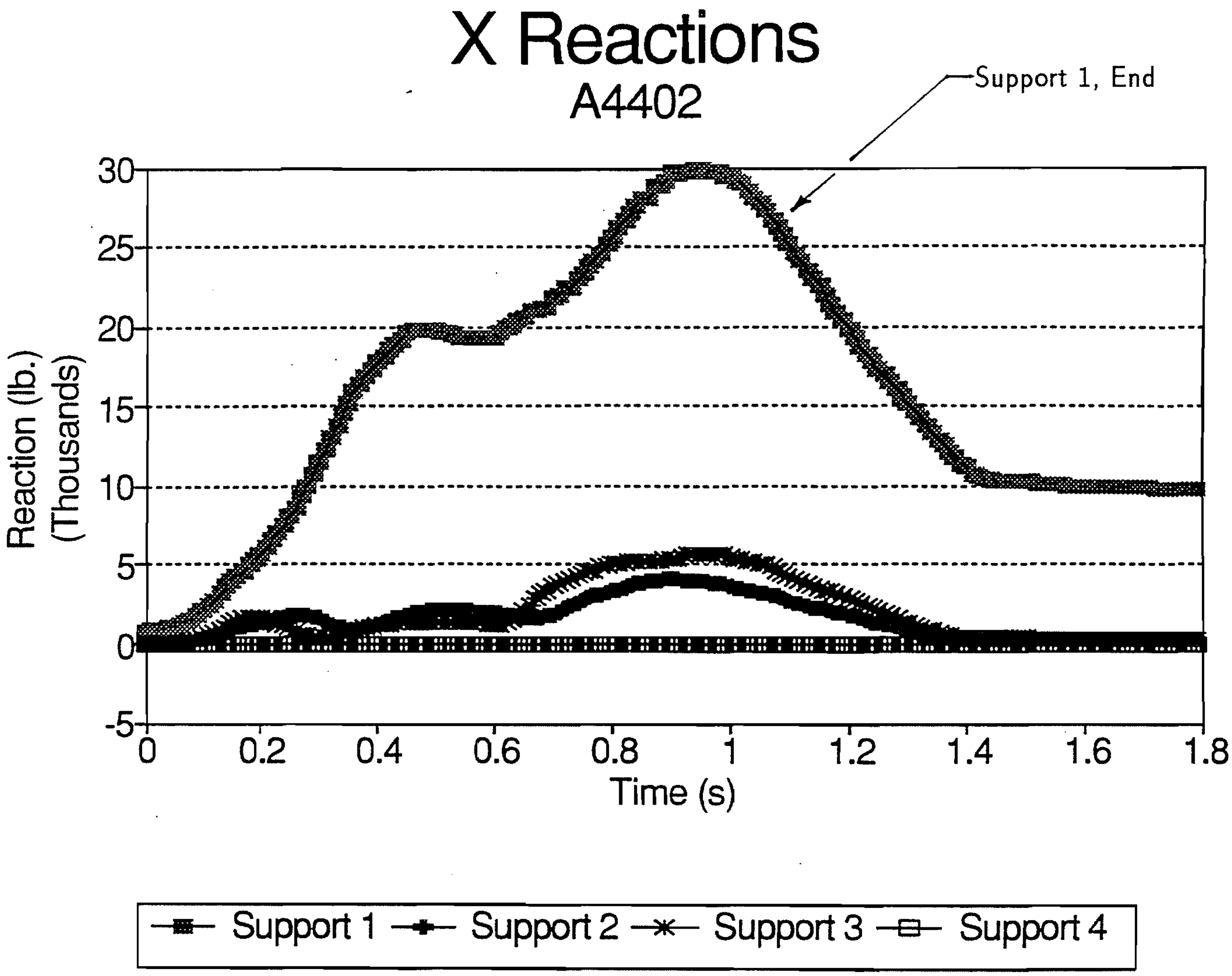
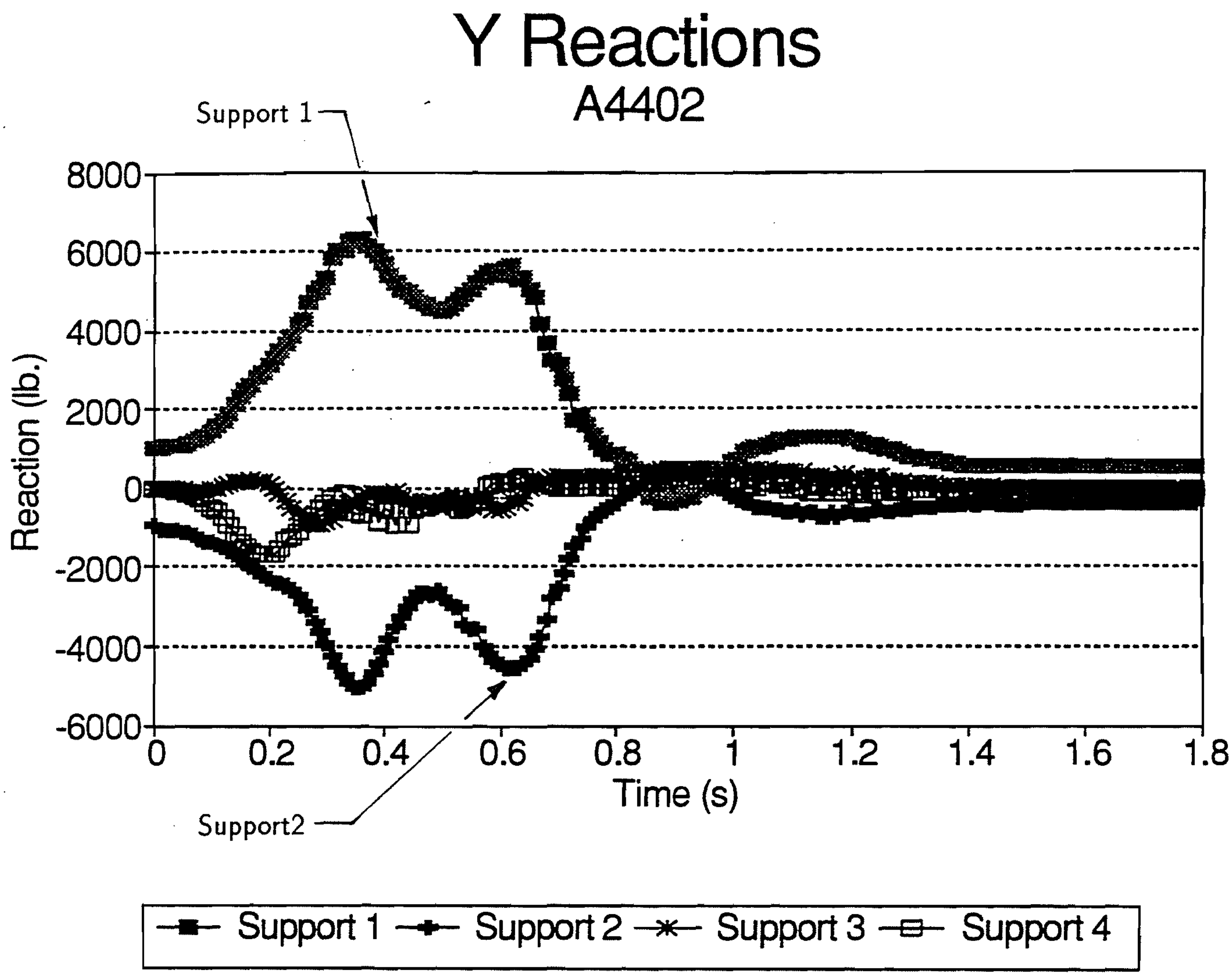


Figure III - 13
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model A.S



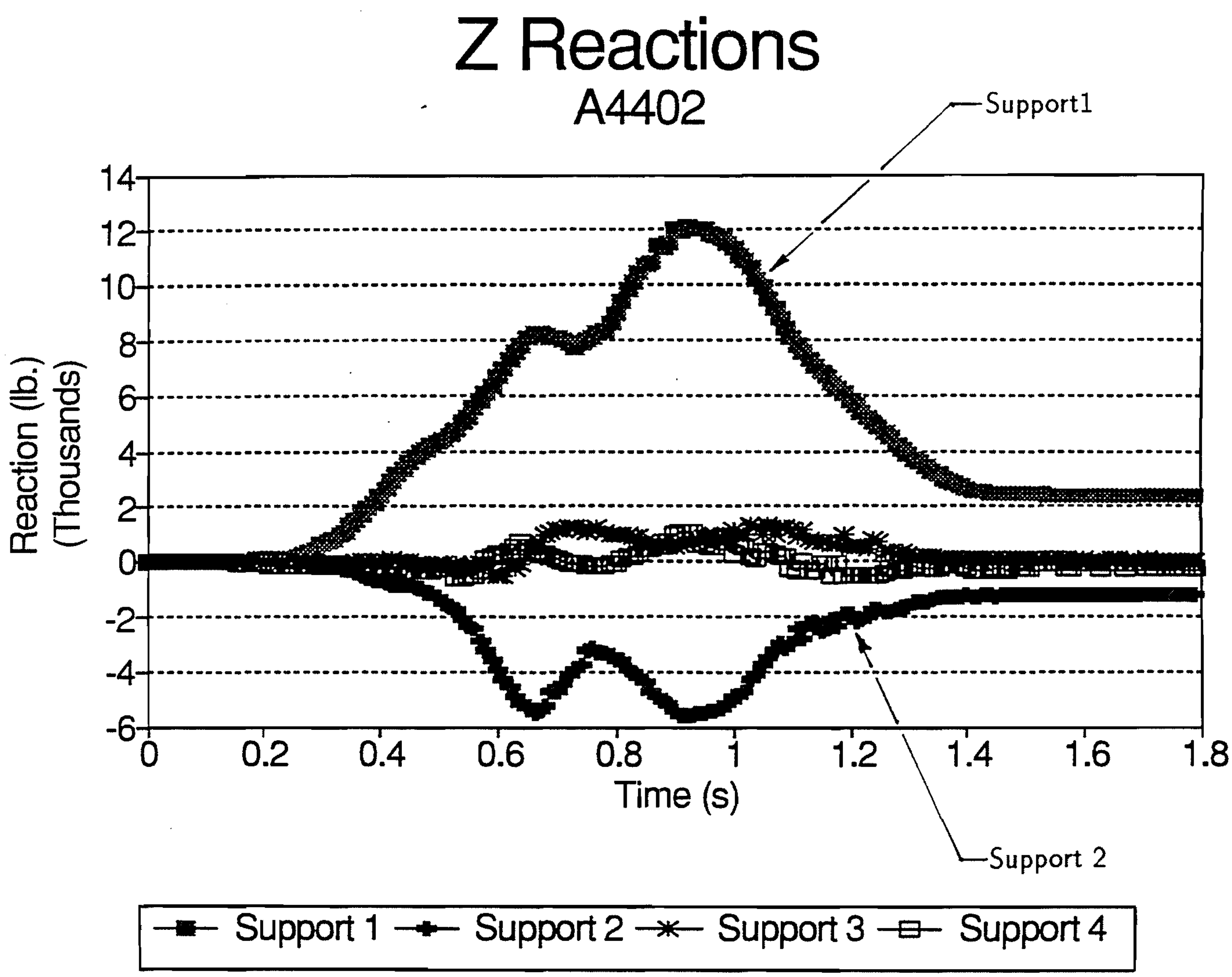
X Reaction, in-plane

Figure III - 14
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model A.S



Y Reaction, Vertical

Figure III - 15
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model A.S



Z Reaction, Downslope

Figure III - 16
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model A.S

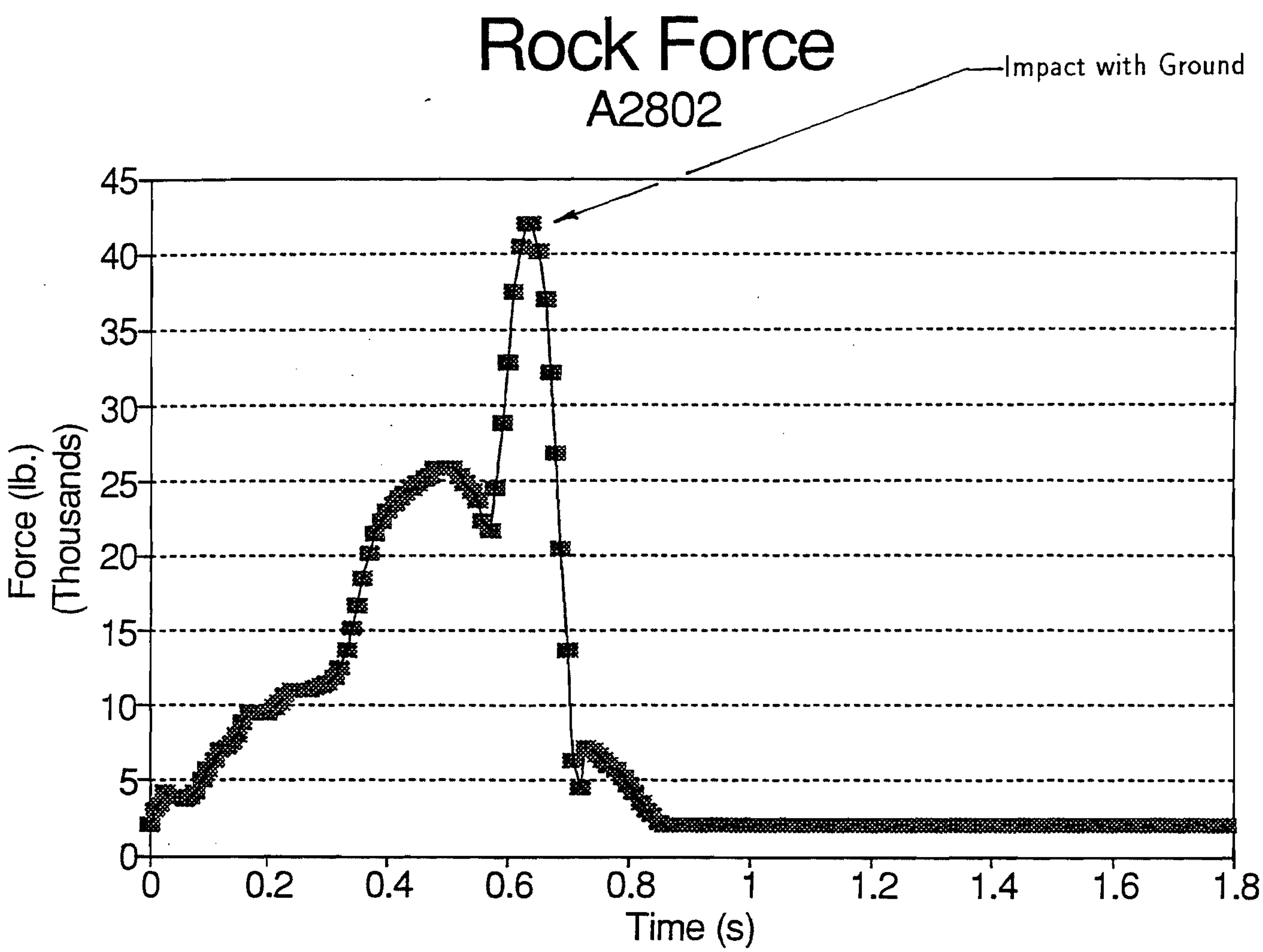


Figure III - 17
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model A.S

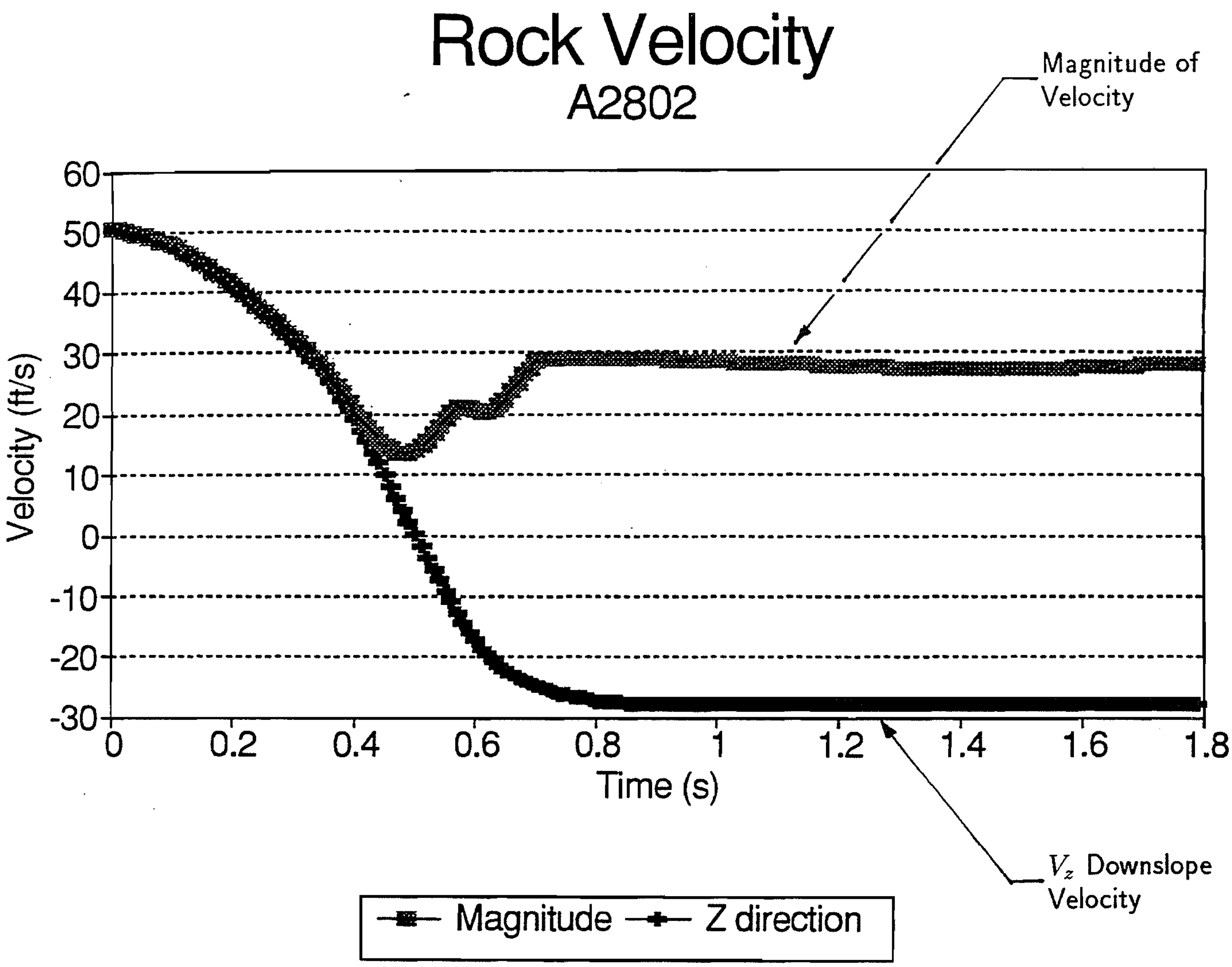


Figure III - 18
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model A.S

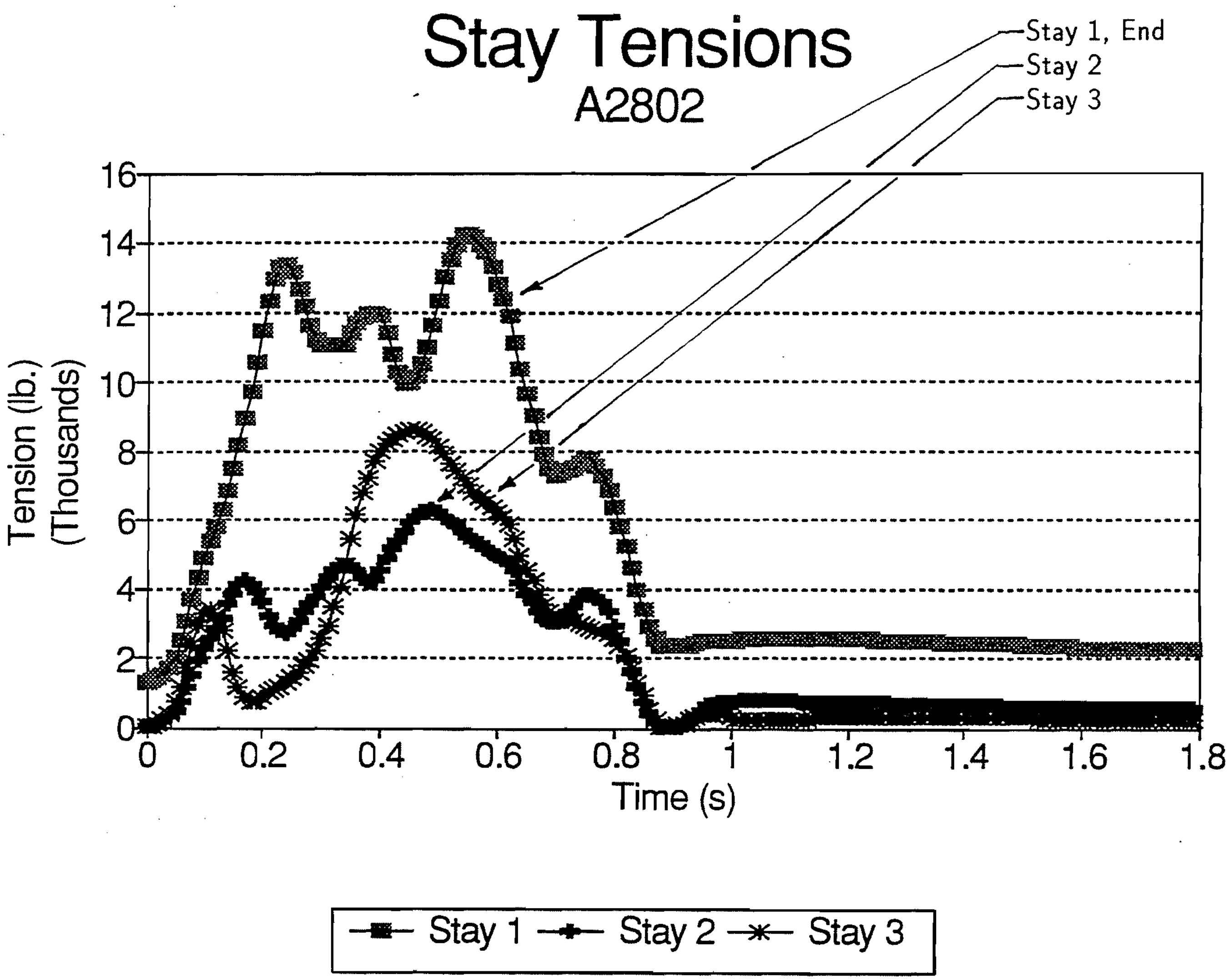


Figure III - 19
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model A.S

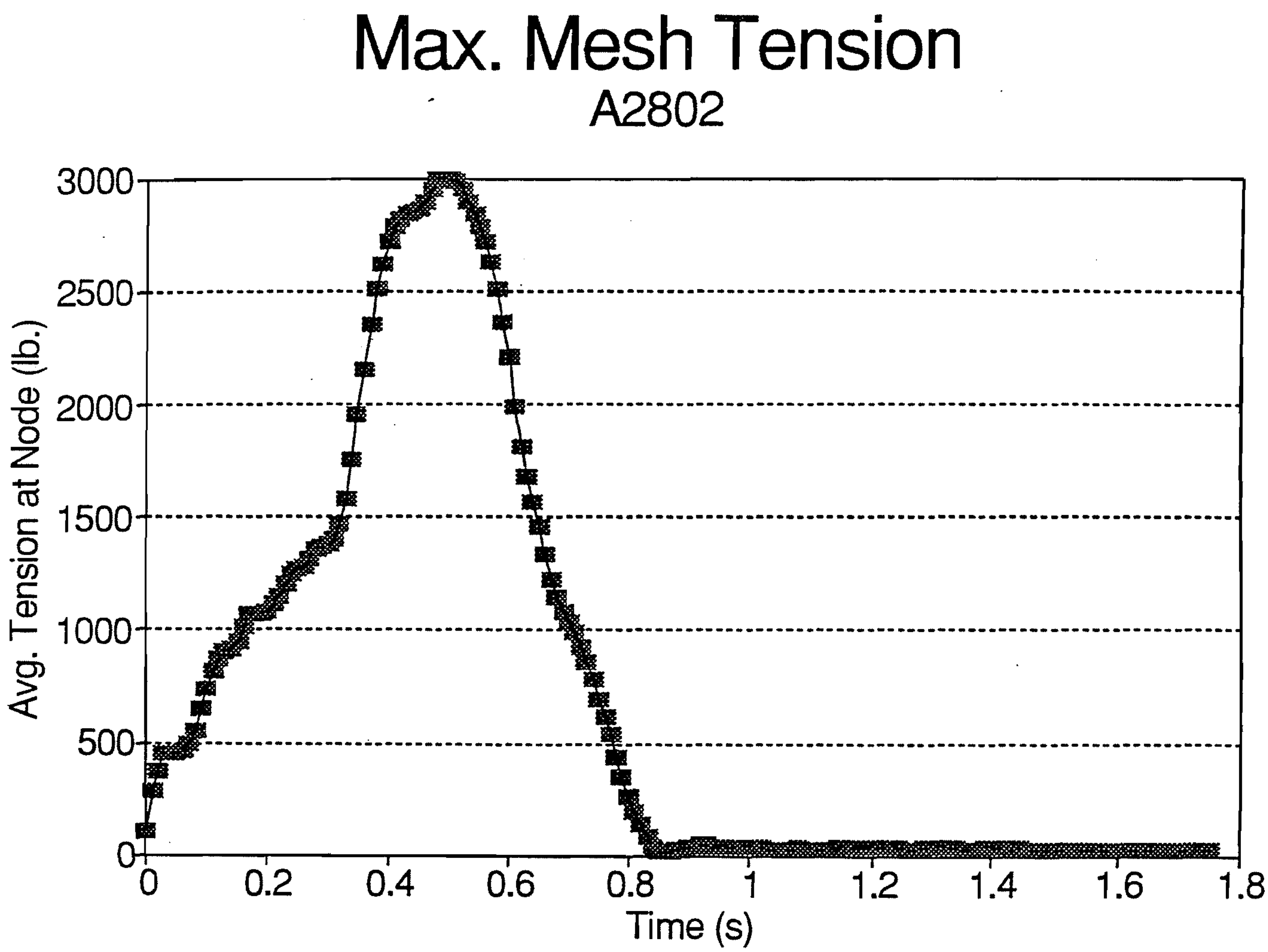


Figure III - 20
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model A.S

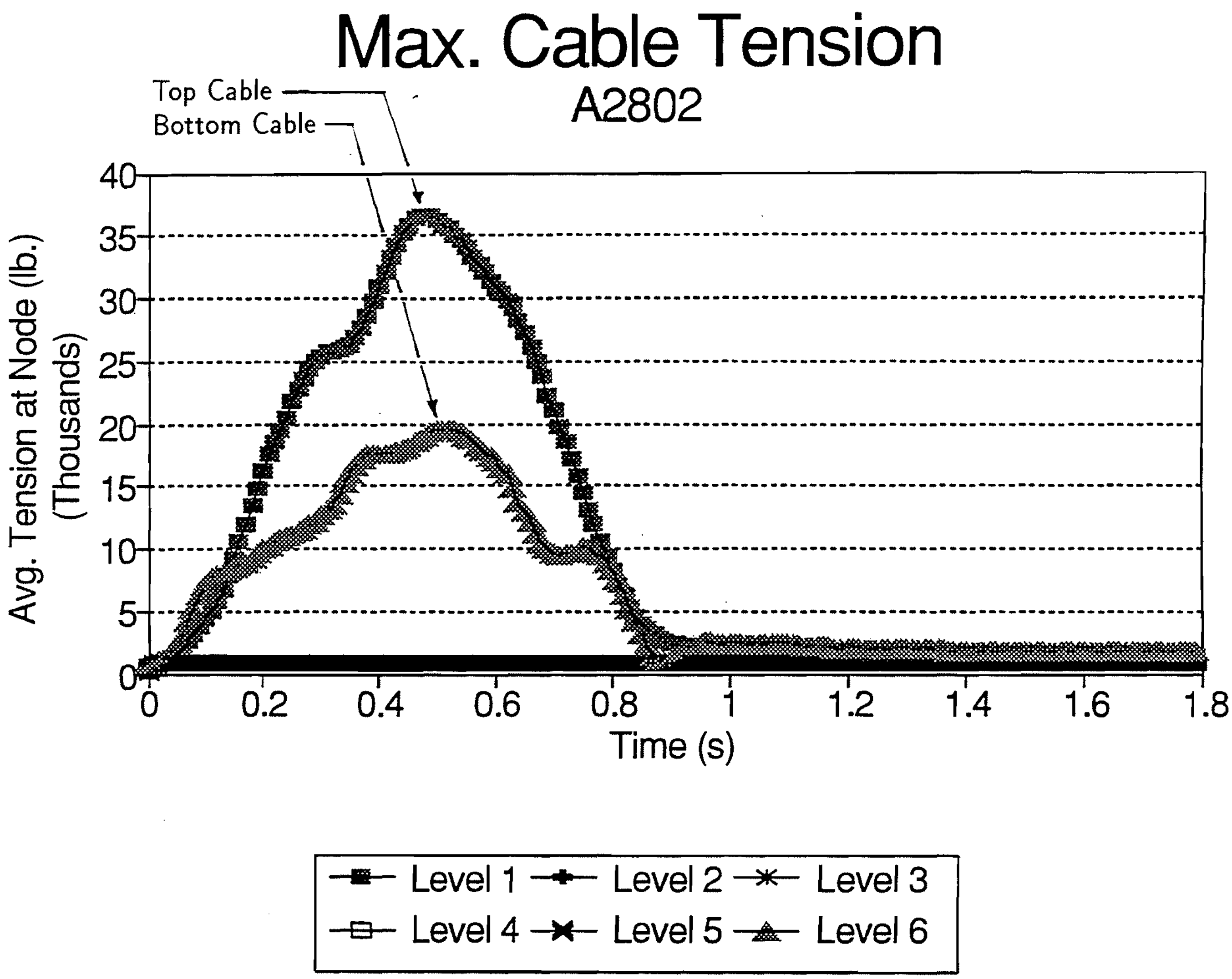
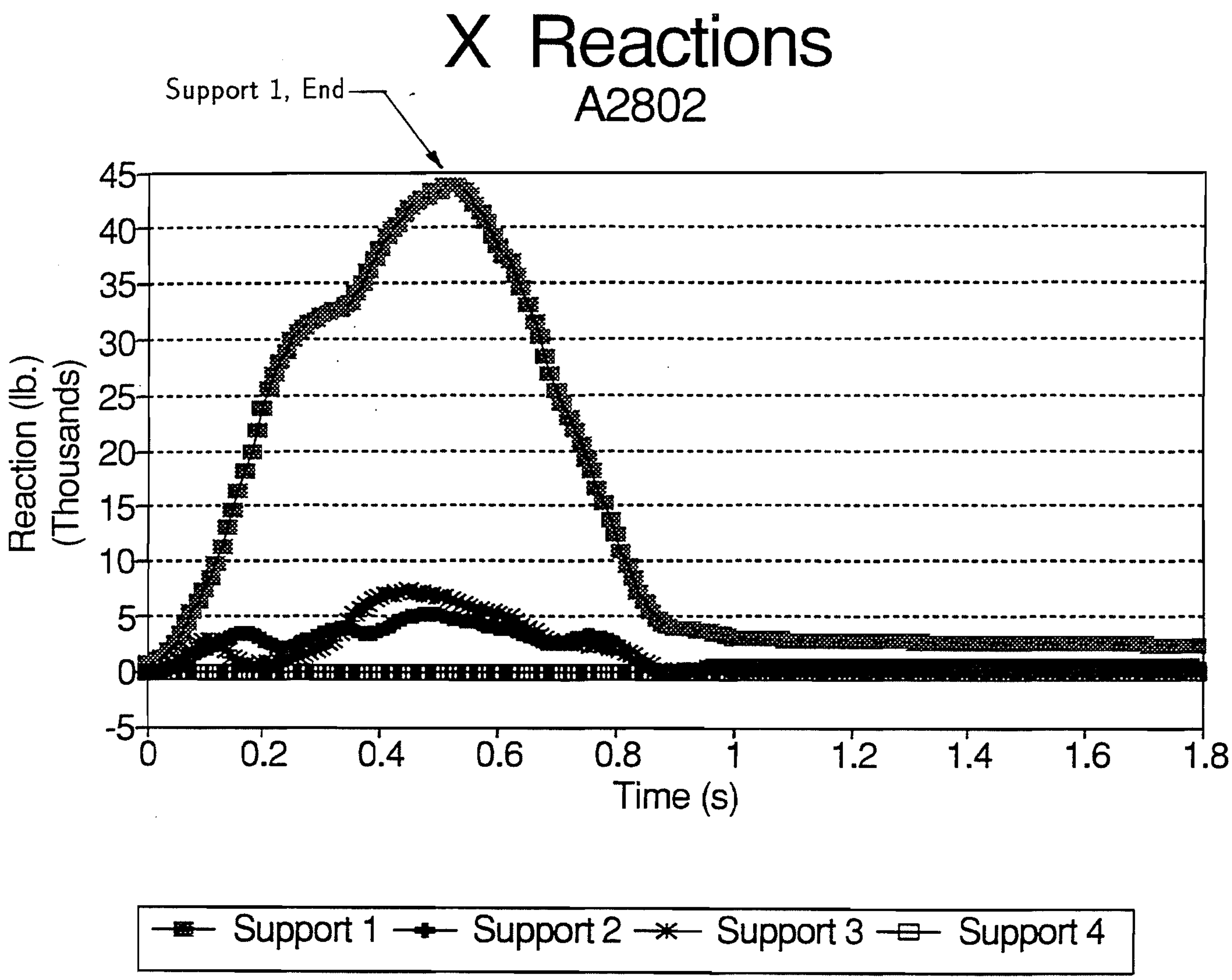
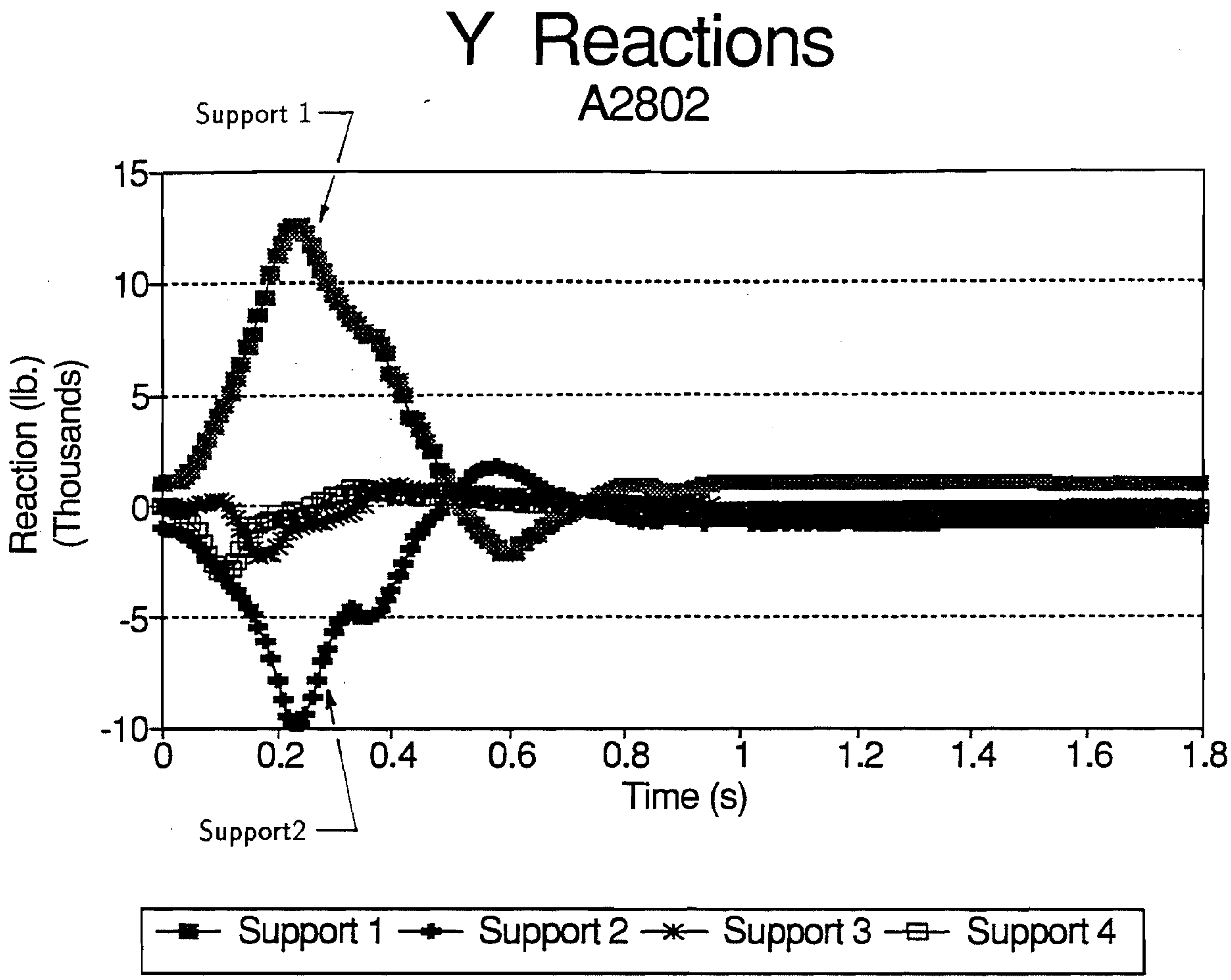


Figure III - 21
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model A.S



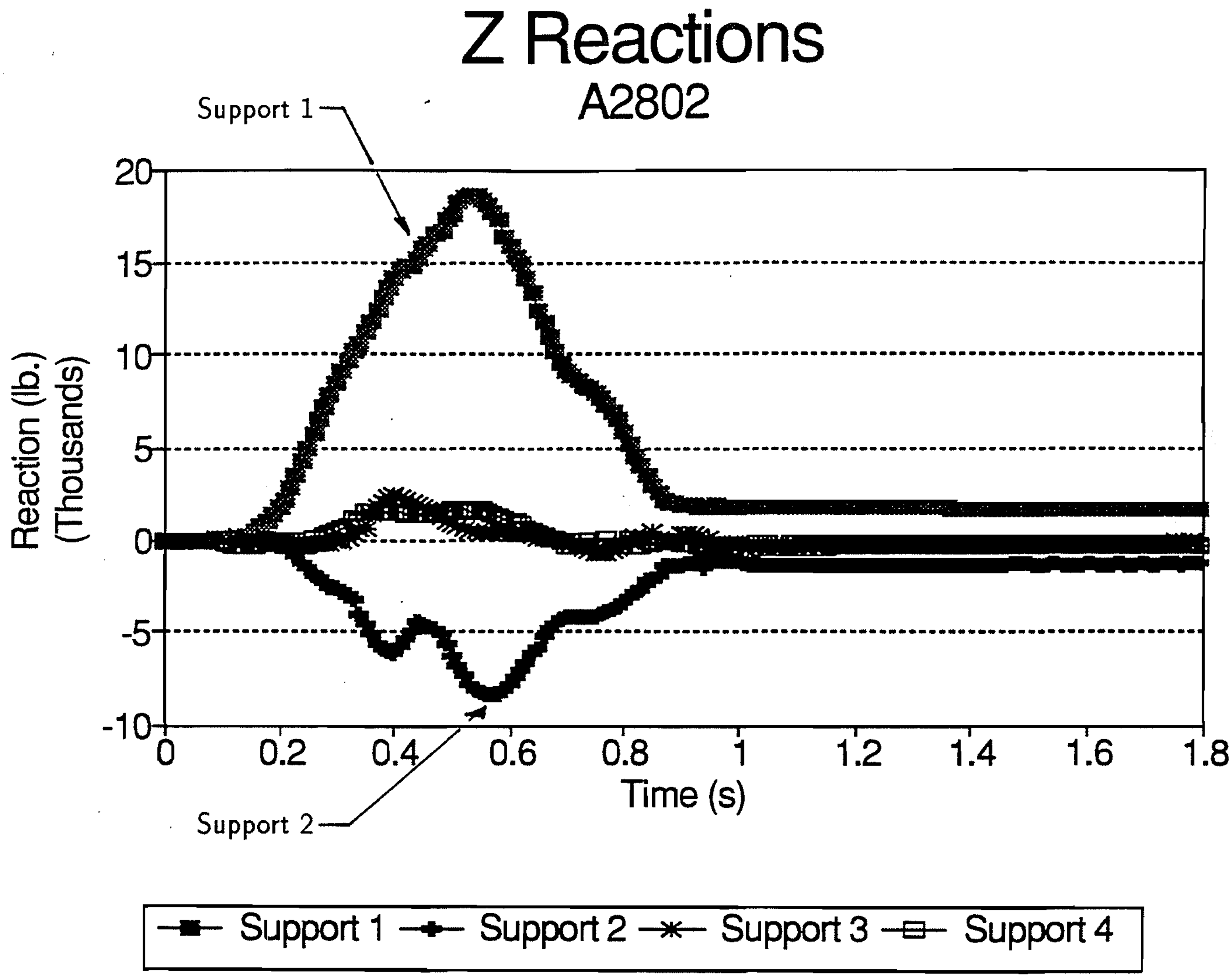
X Reaction, in-plane

Figure III - 22
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model A.S



Y Reaction, Vertical

Figure III - 23
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model A.S



Z Reaction, Downslope

Figure III - 24
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model A.S

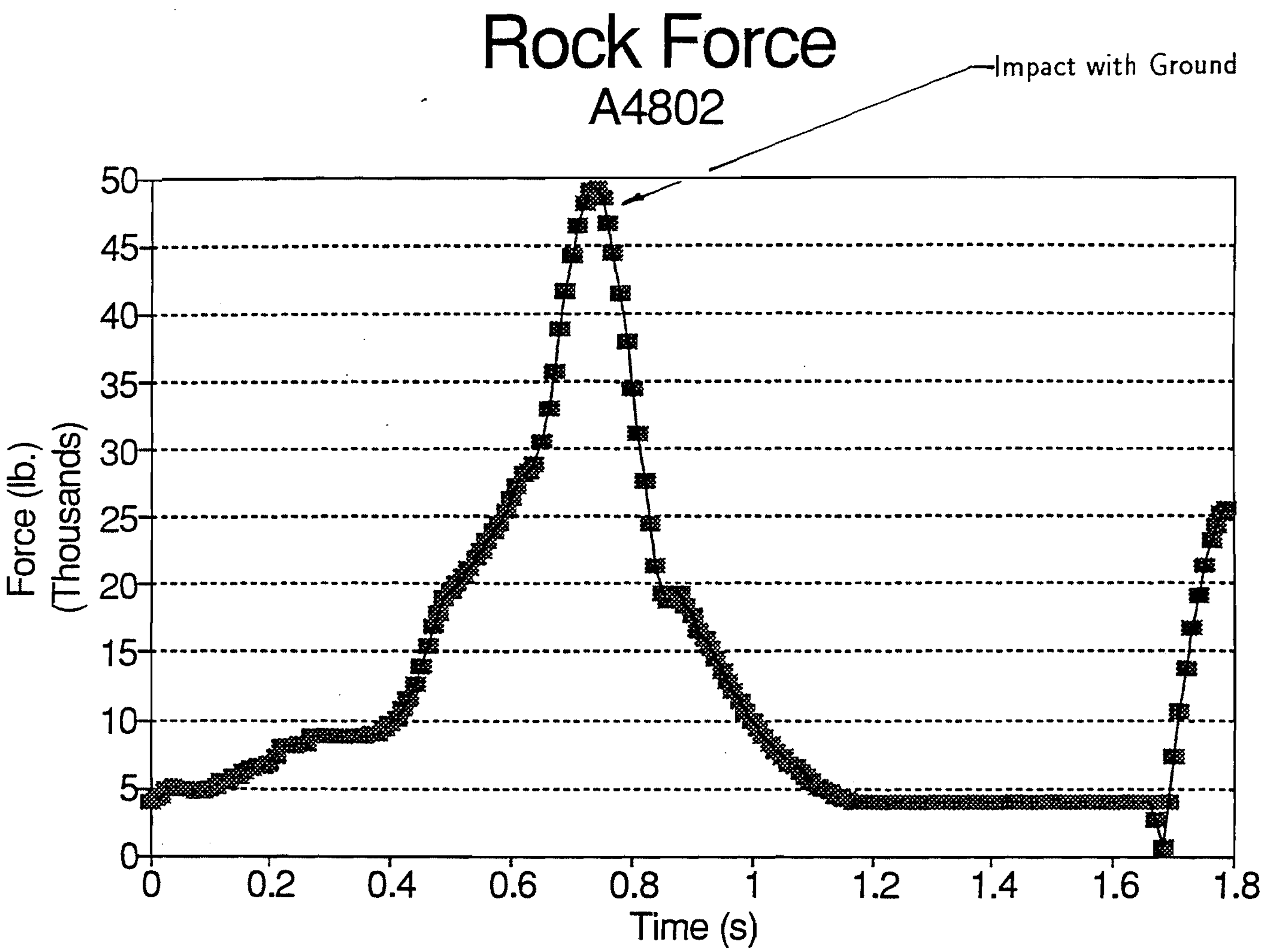


Figure III - 25
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model A.S

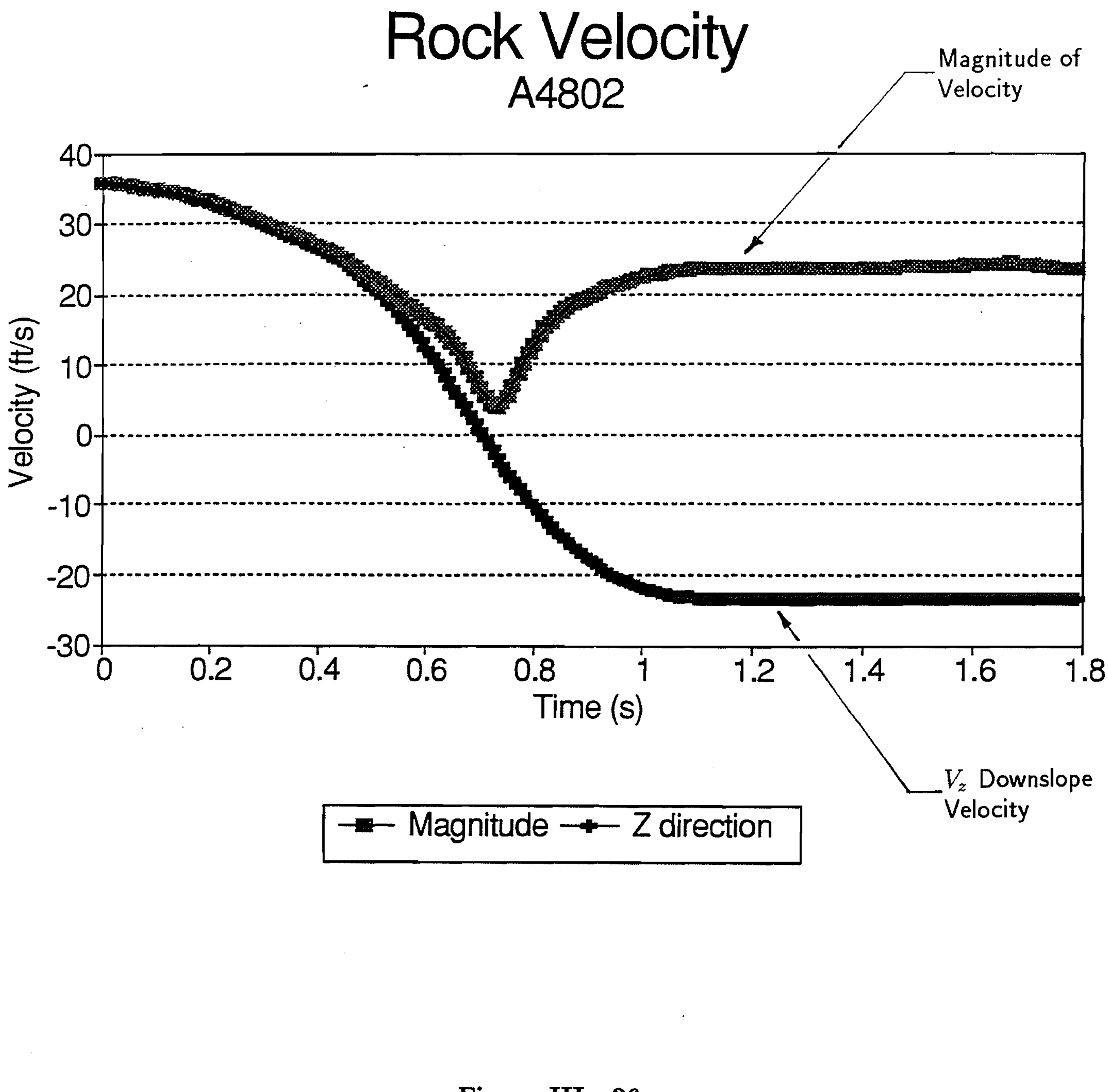


Figure III - 26
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model A.S

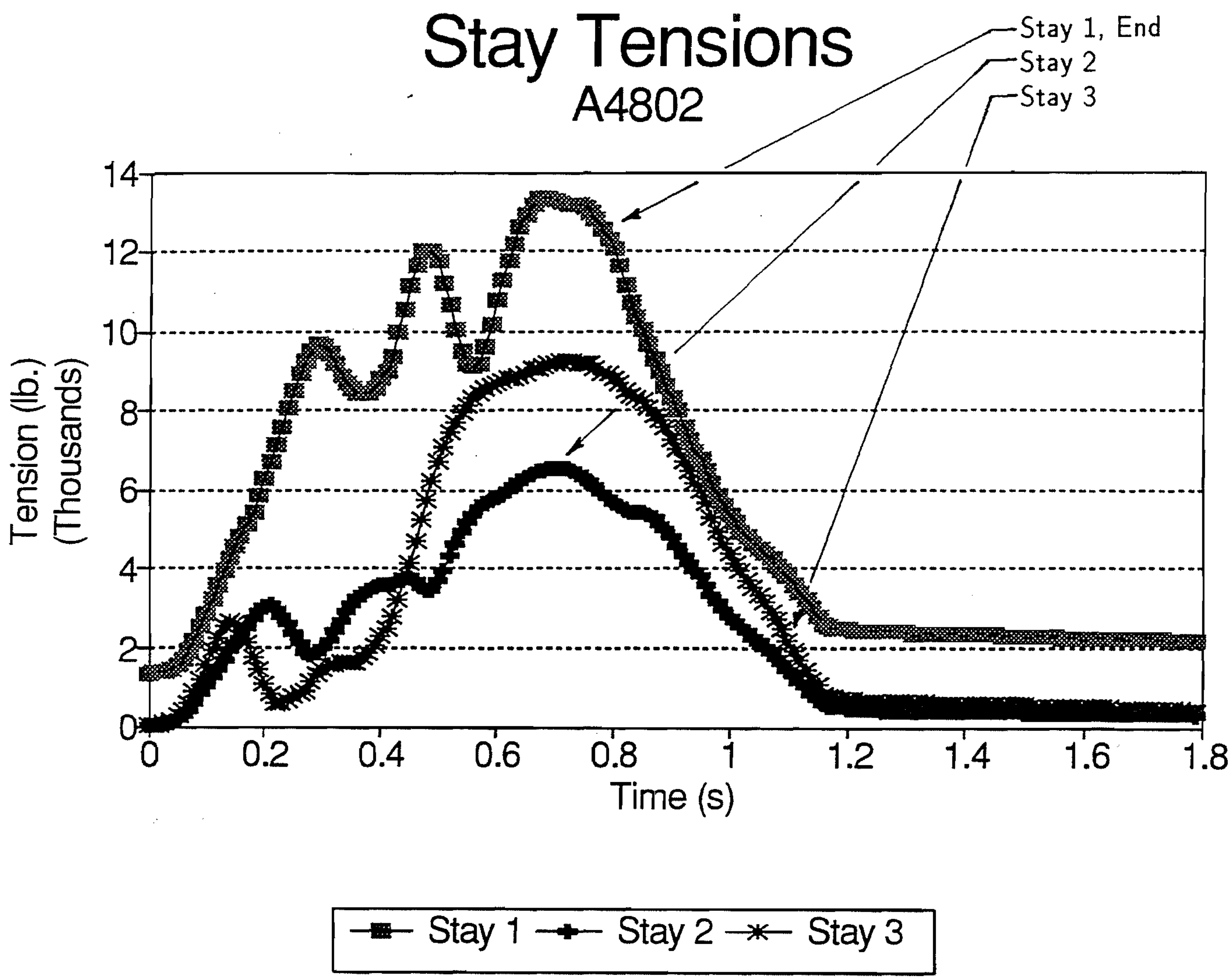


Figure III - 27
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model A.S

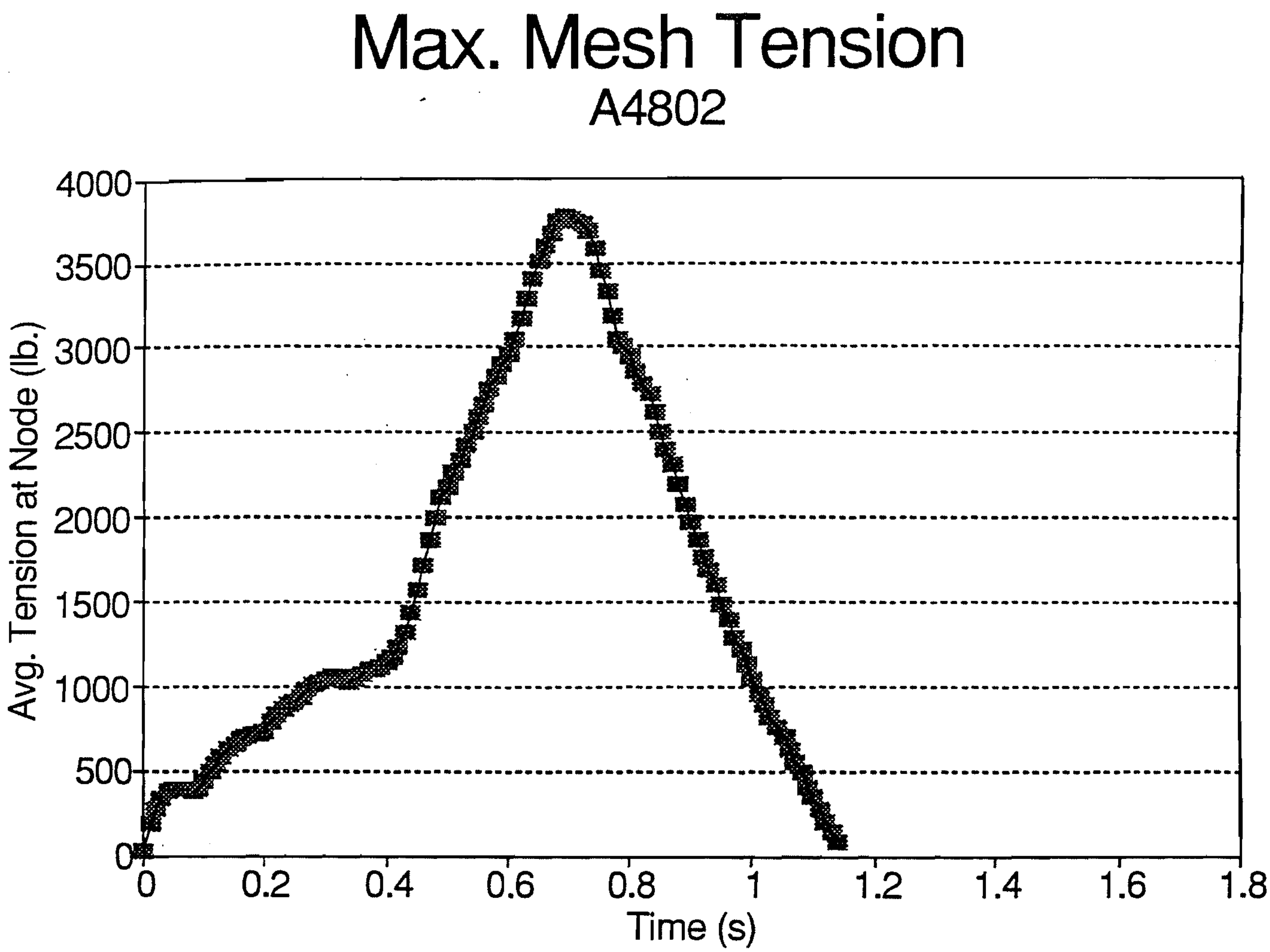


Figure III - 28
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model A.S

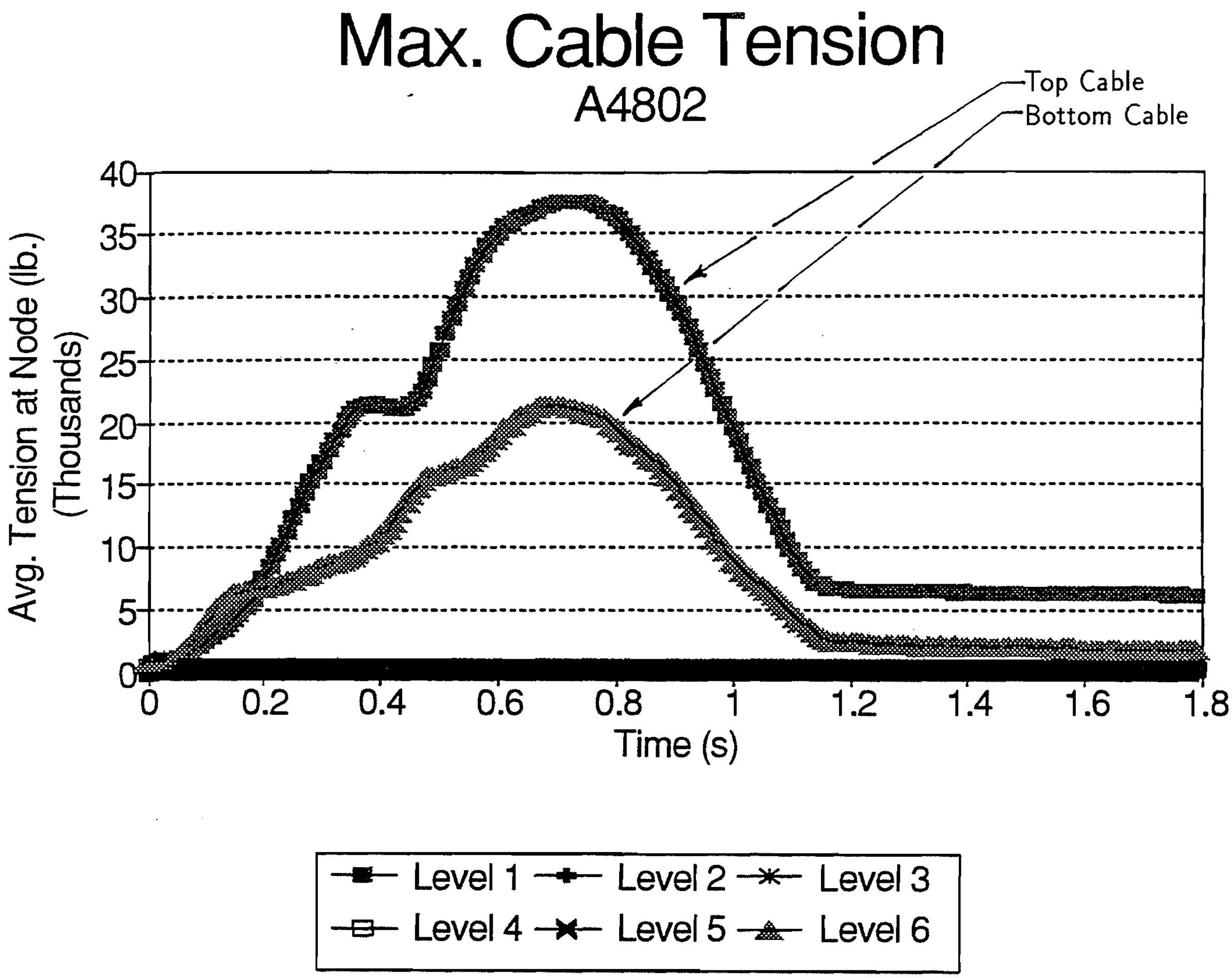
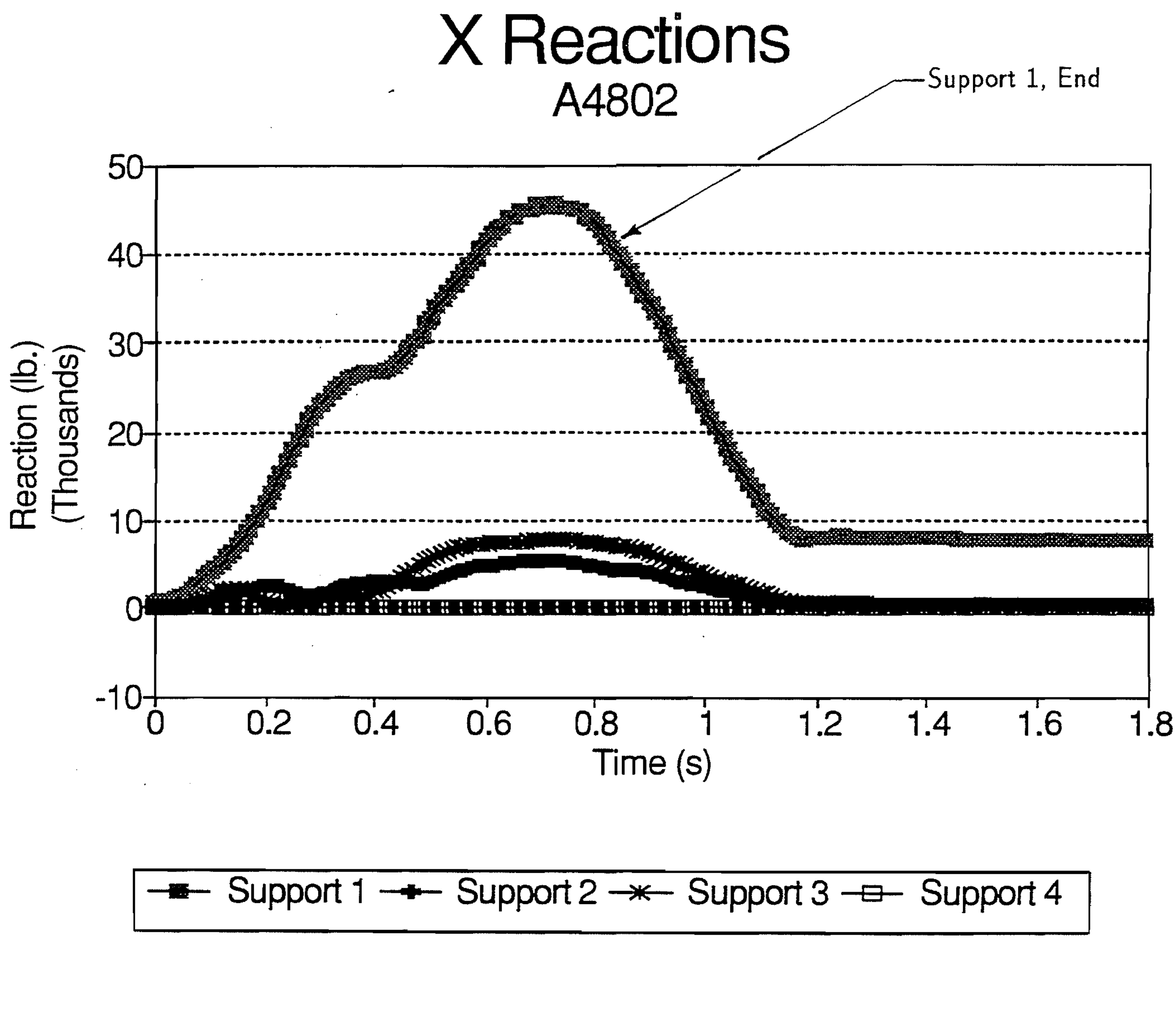
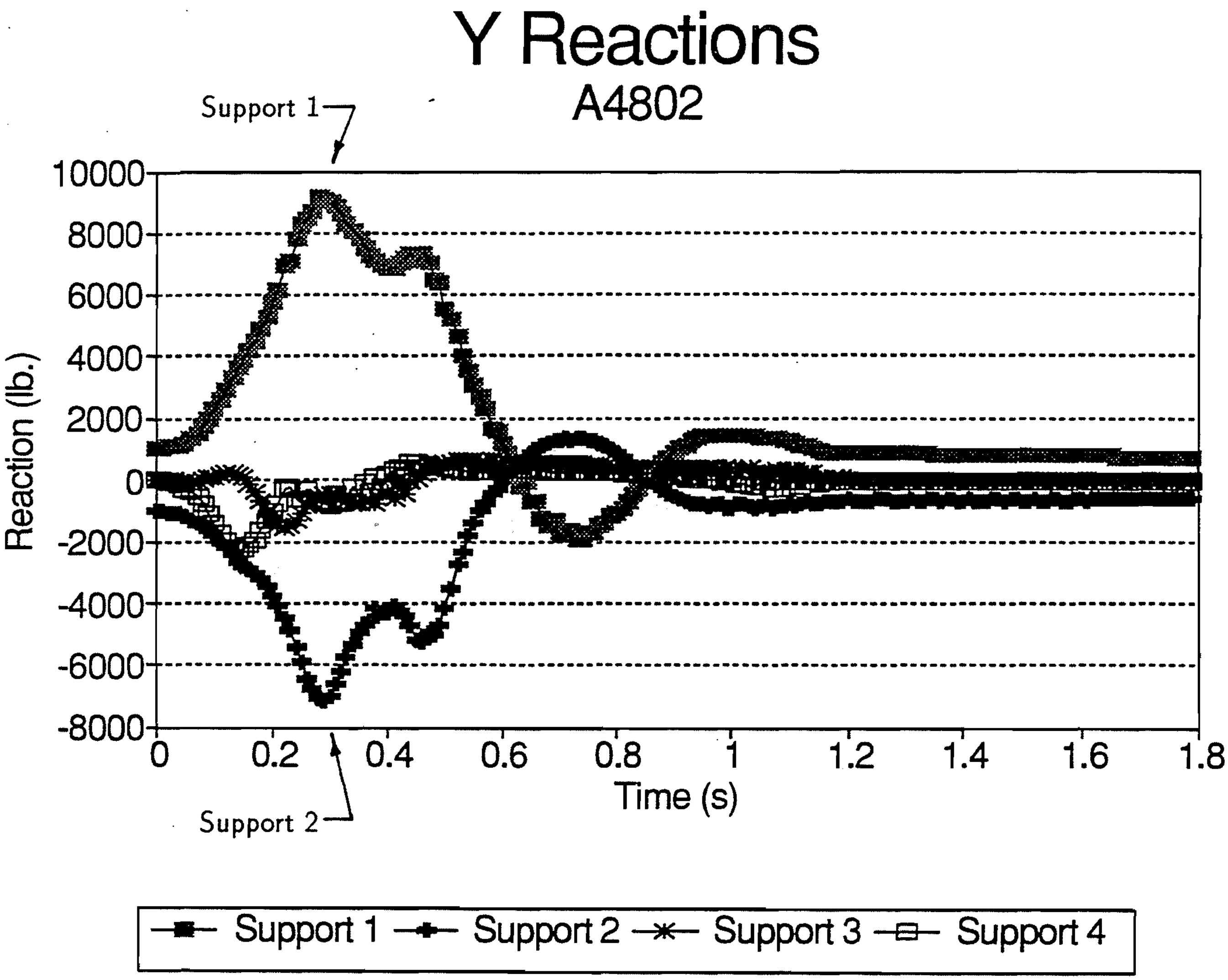


Figure III - 29
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model A.S



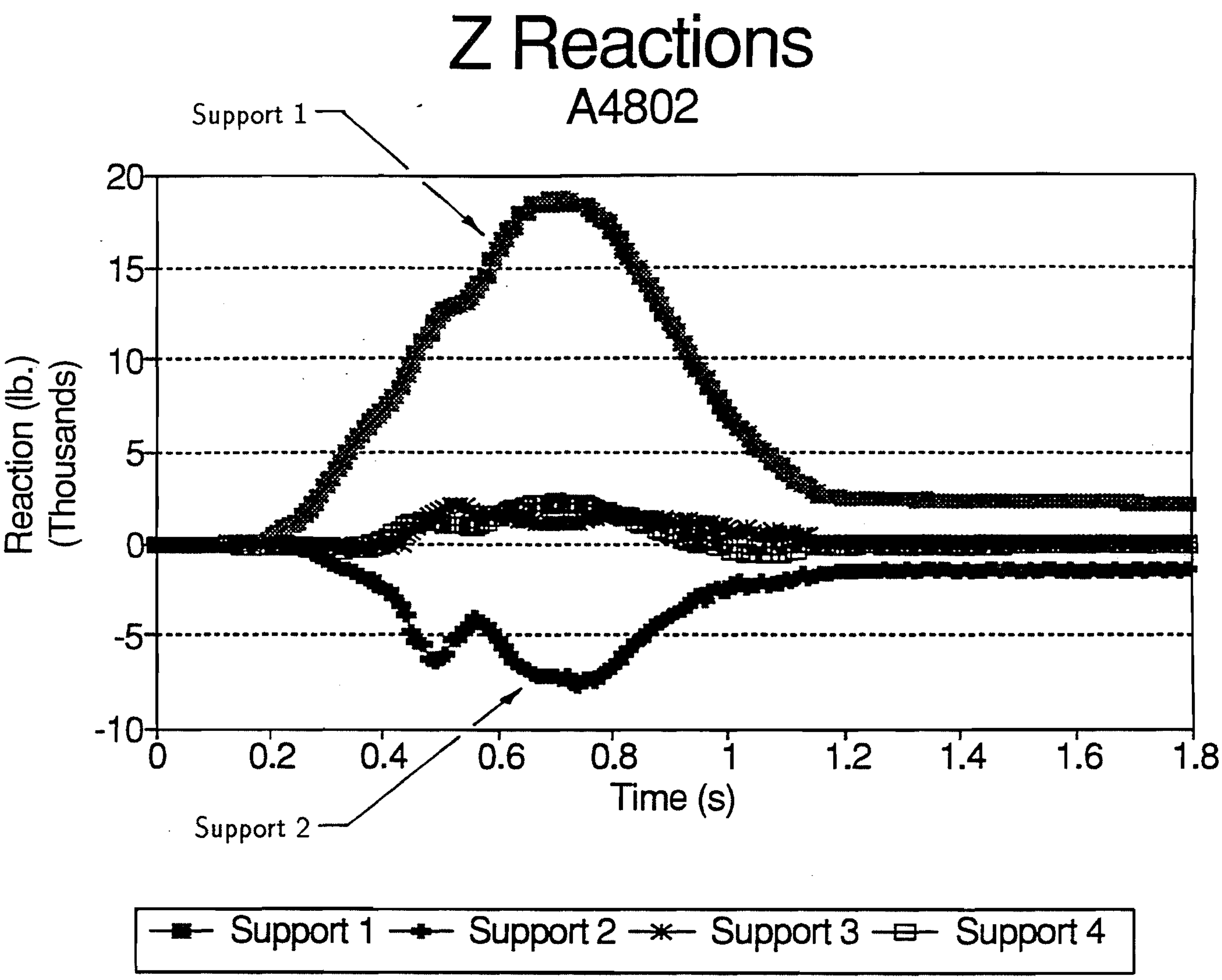
X Reaction, in-plane

Figure III - 30
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model A.S



Y Reaction, Vertical

Figure III - 31
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model A.S



Z Reaction, Downslope

Figure III - 32
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model A.S

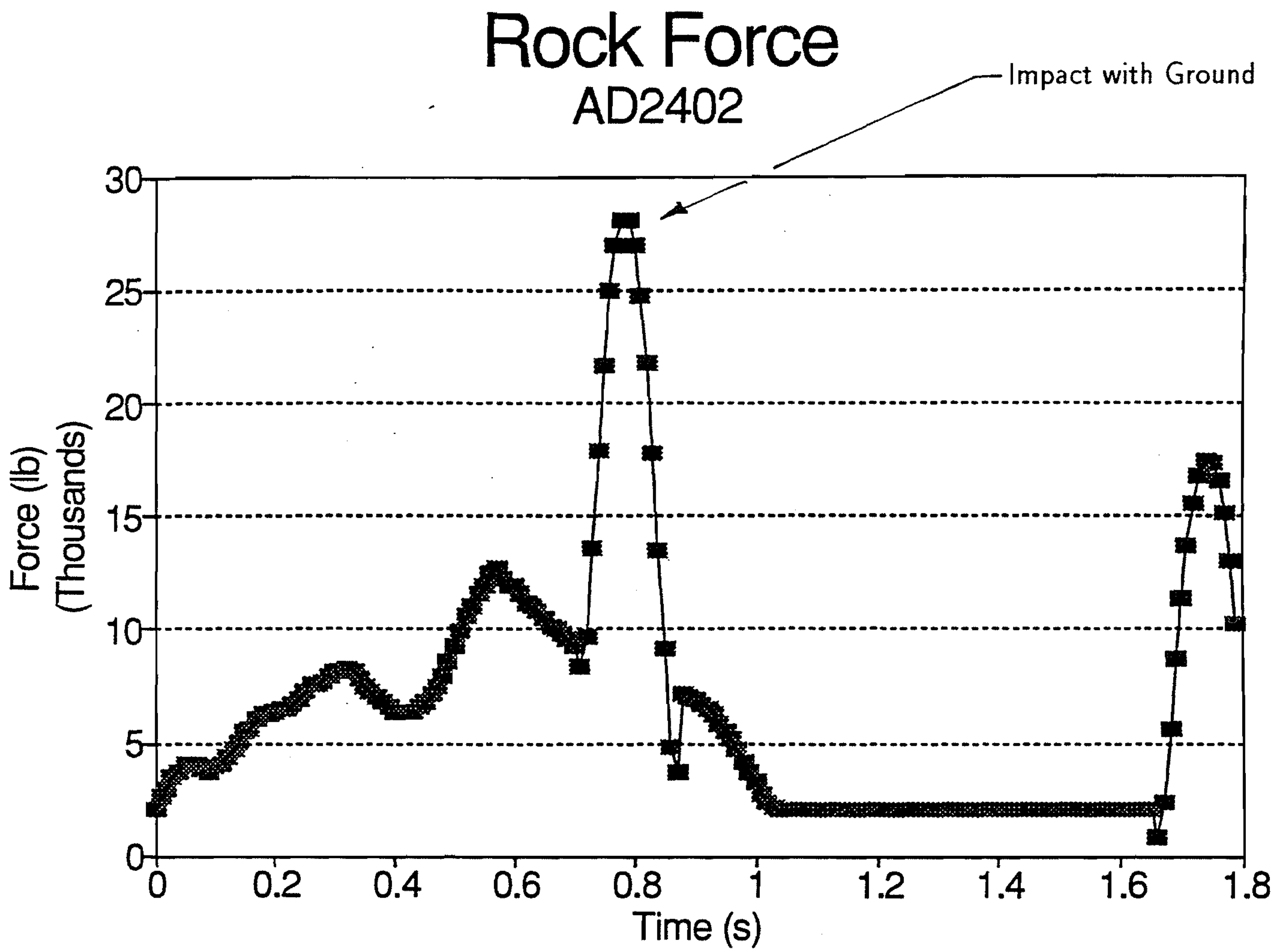


Figure III - 33
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model A.D

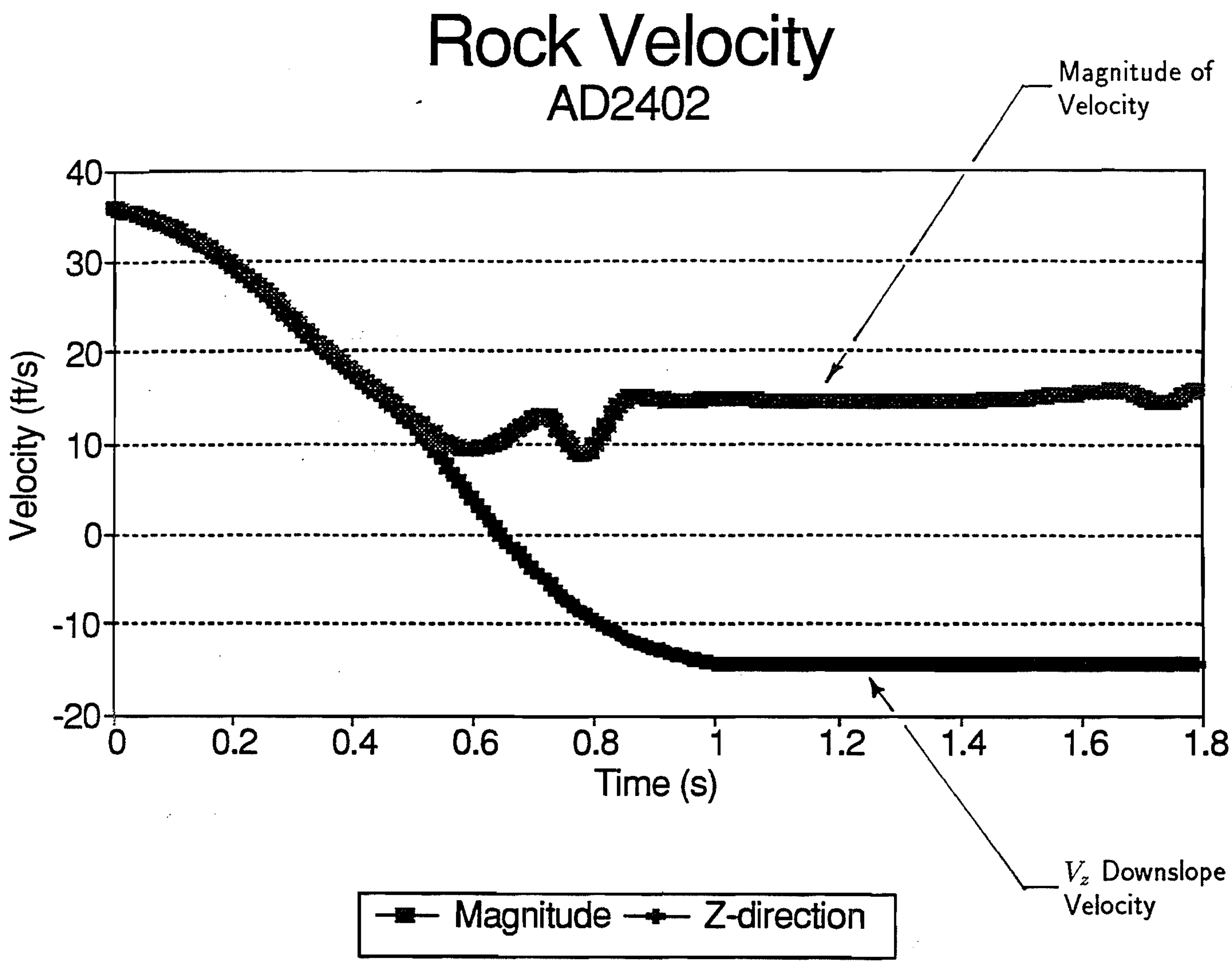


Figure III - 34
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model A.D

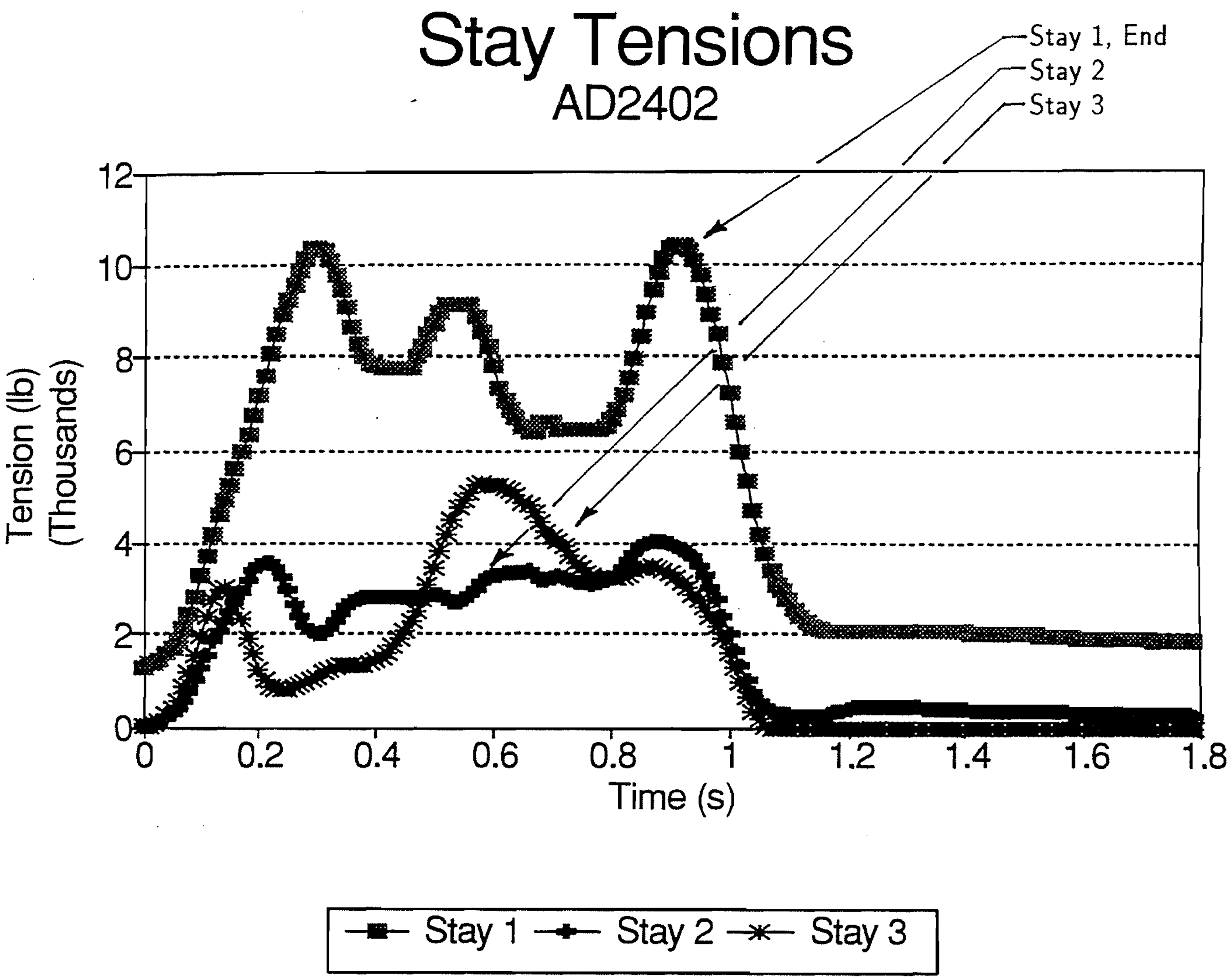


Figure III - 35
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model A.D

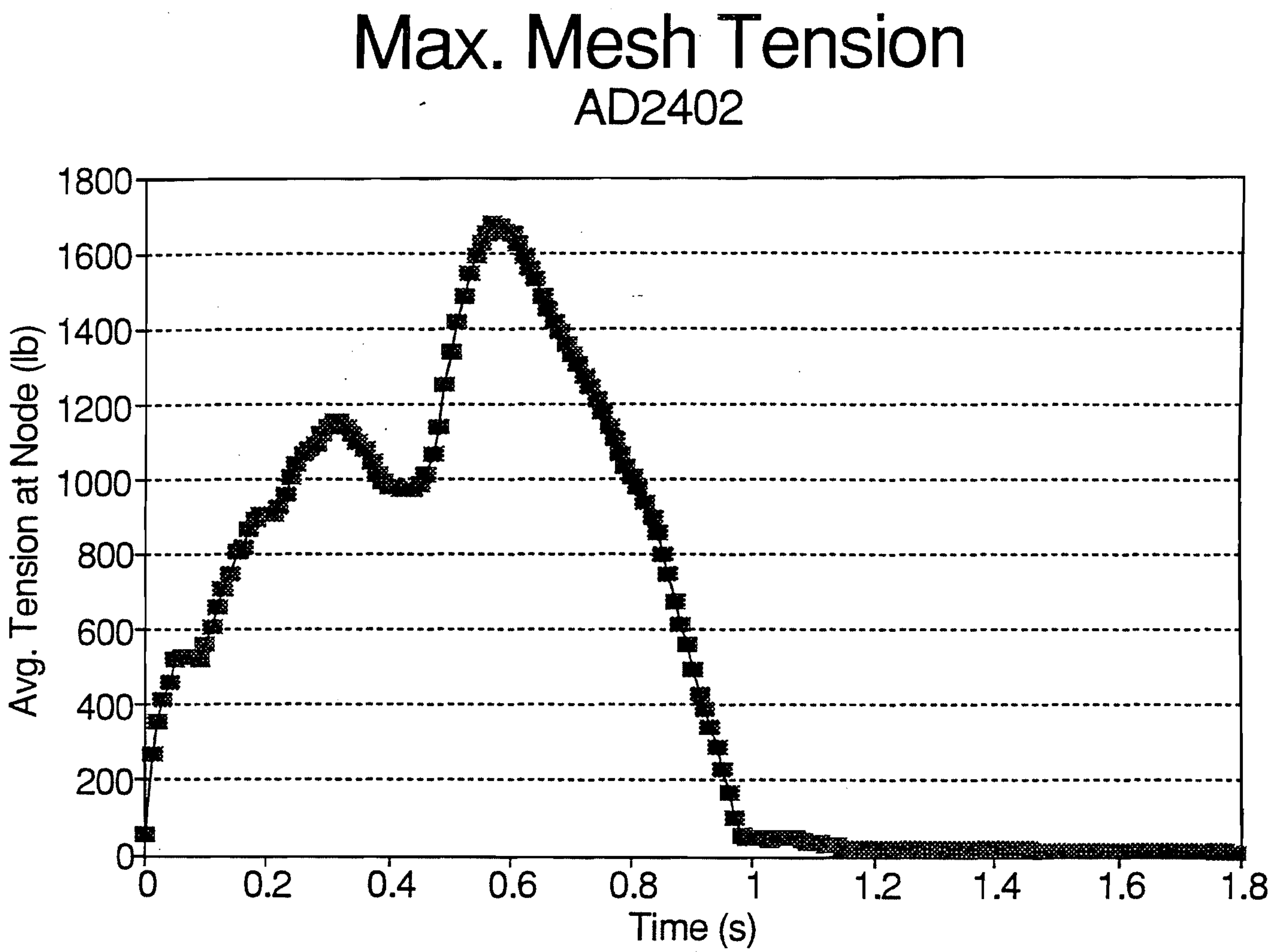


Figure III - 36
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model A.D

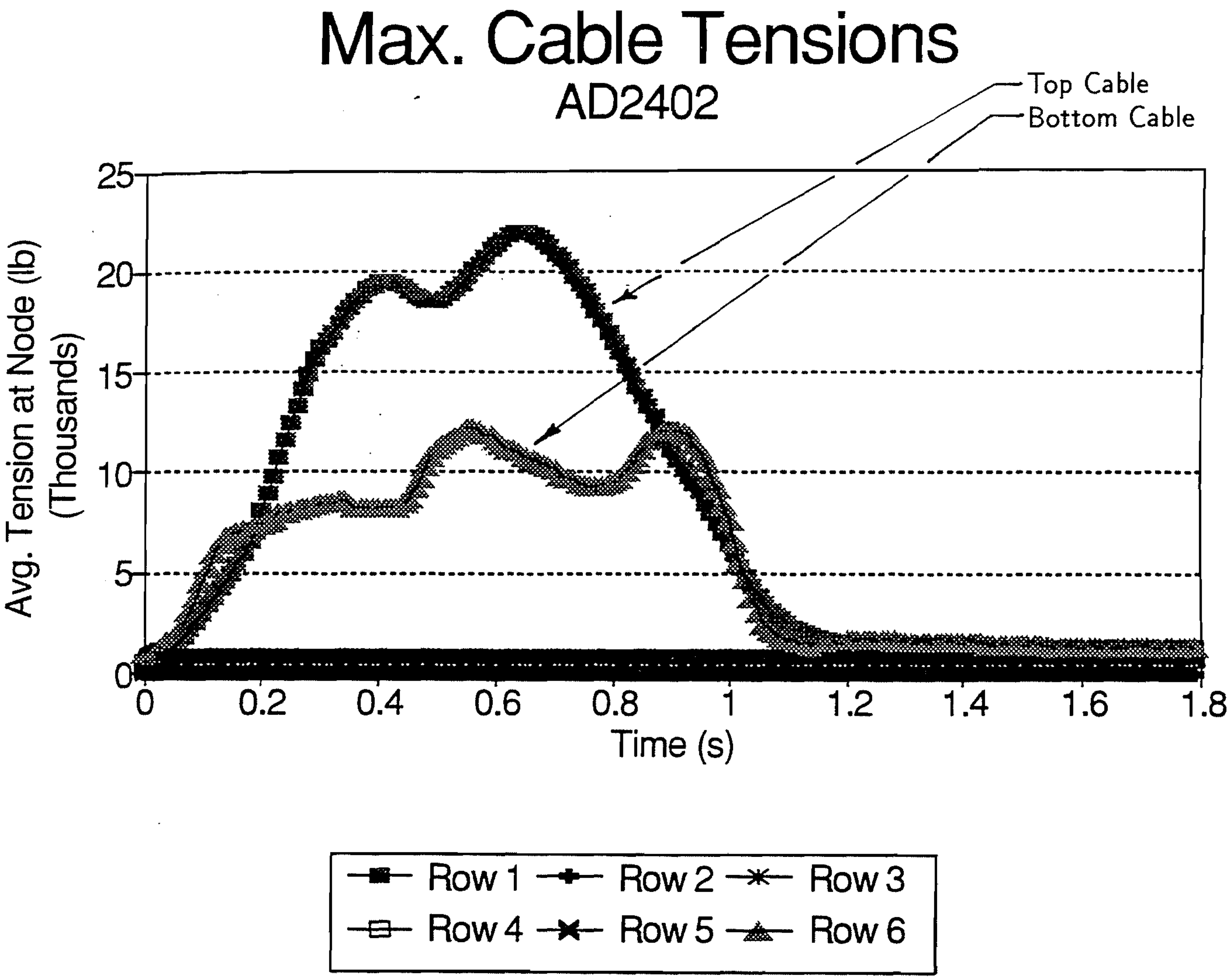
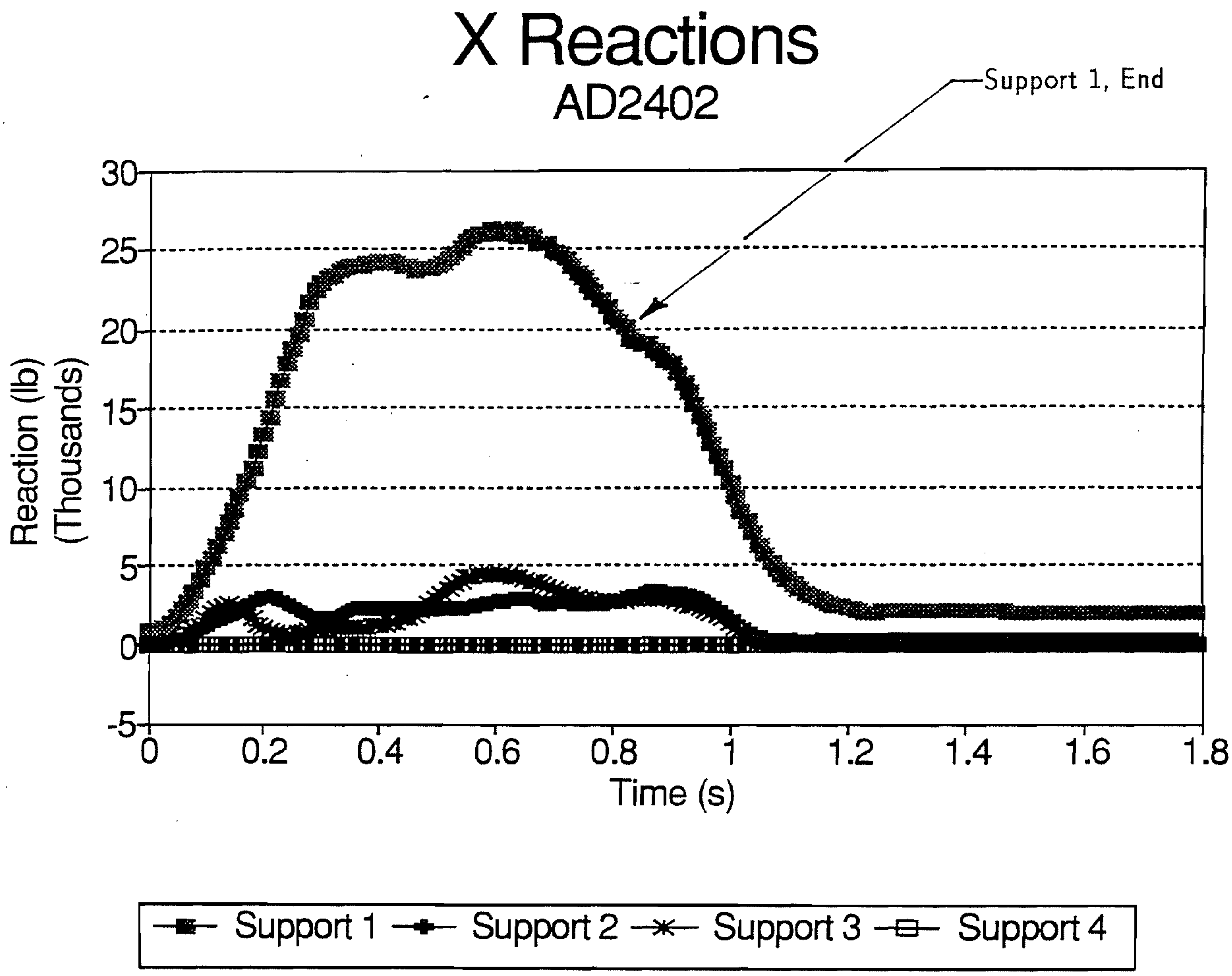
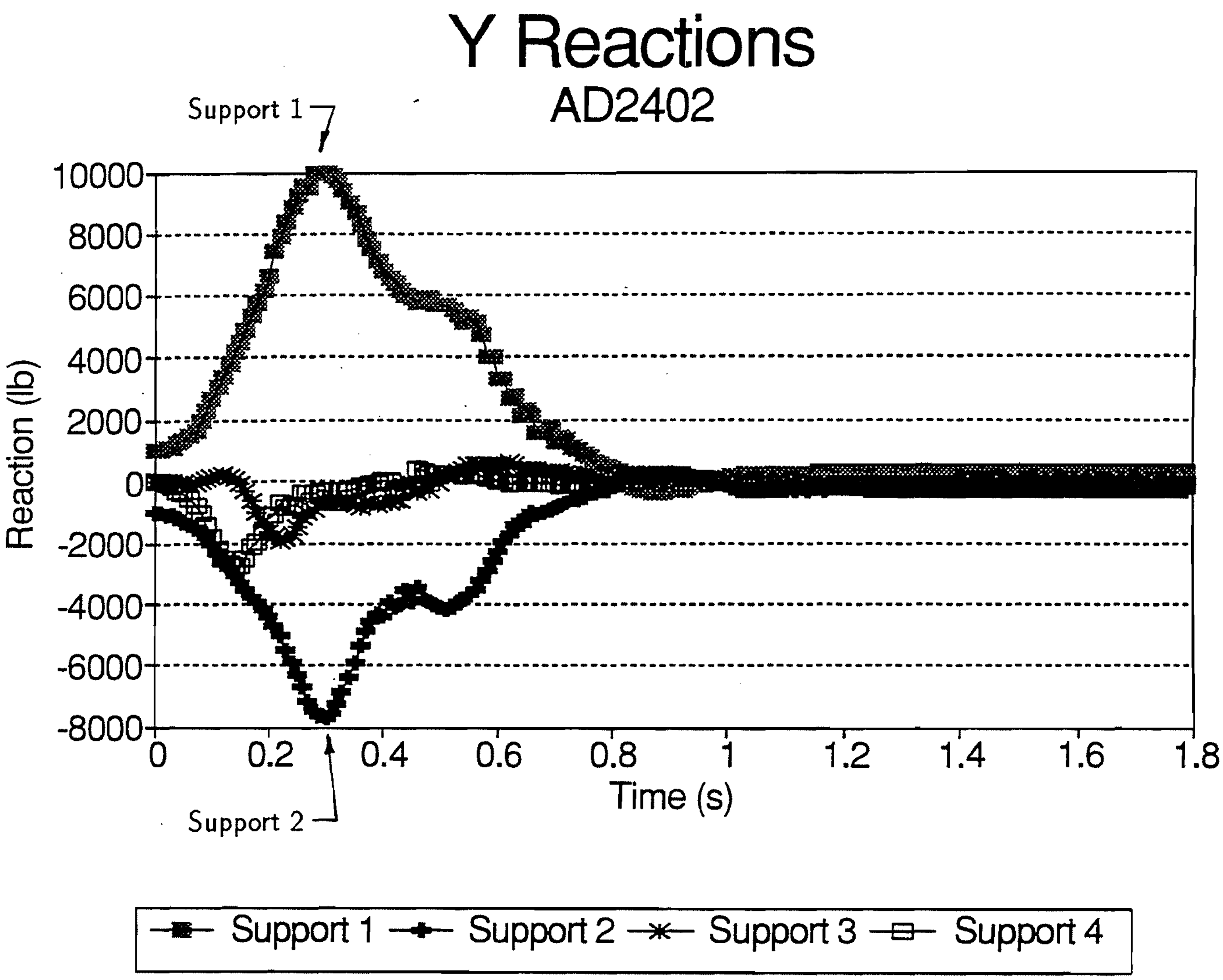


Figure III - 37
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model A.D



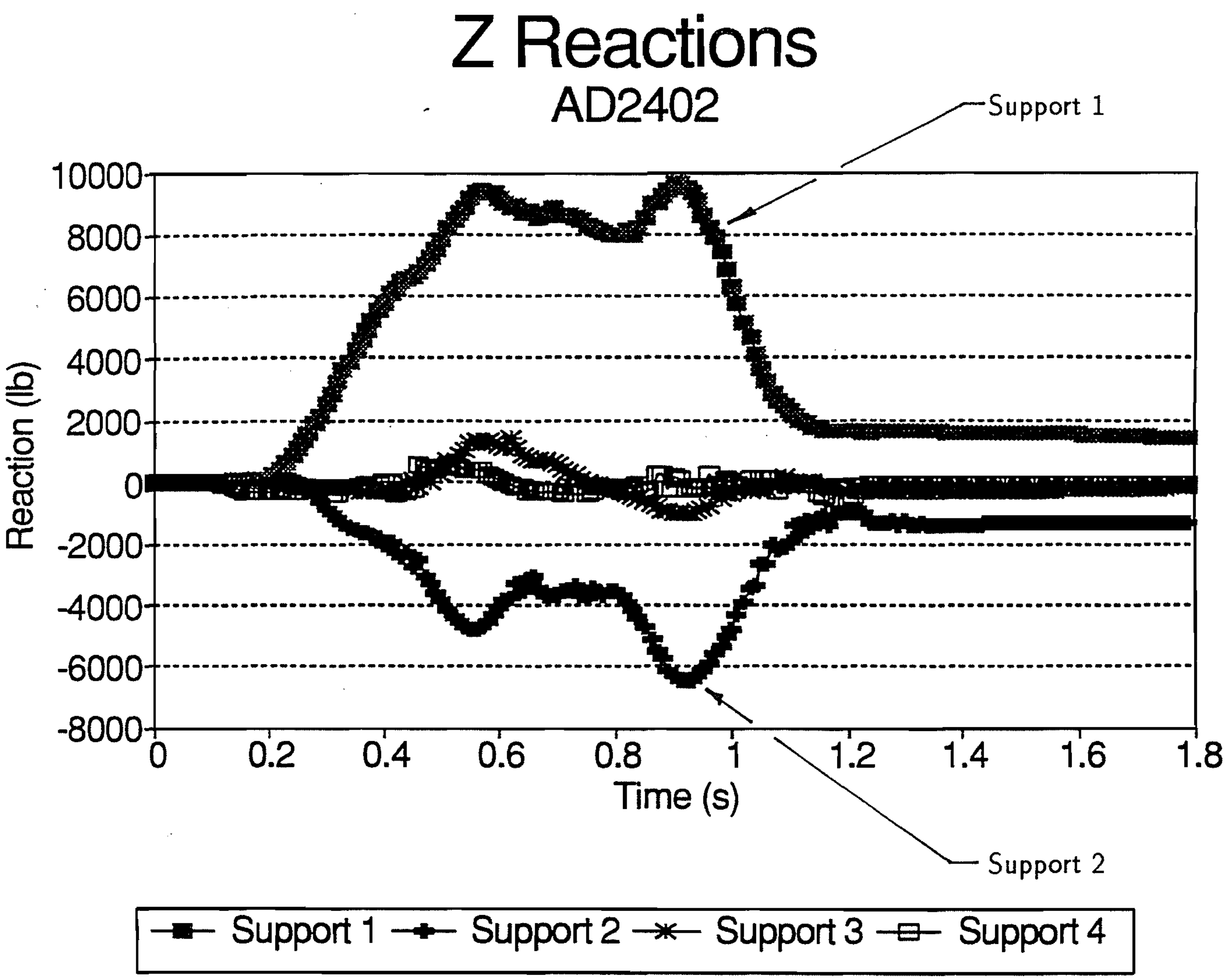
X Reaction, in-plane

Figure III - 38
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model A.D



Y Reaction, Vertical

Figure III - 39
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model A.D



Z Reaction, Downslope

Figure III - 40
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model A.D

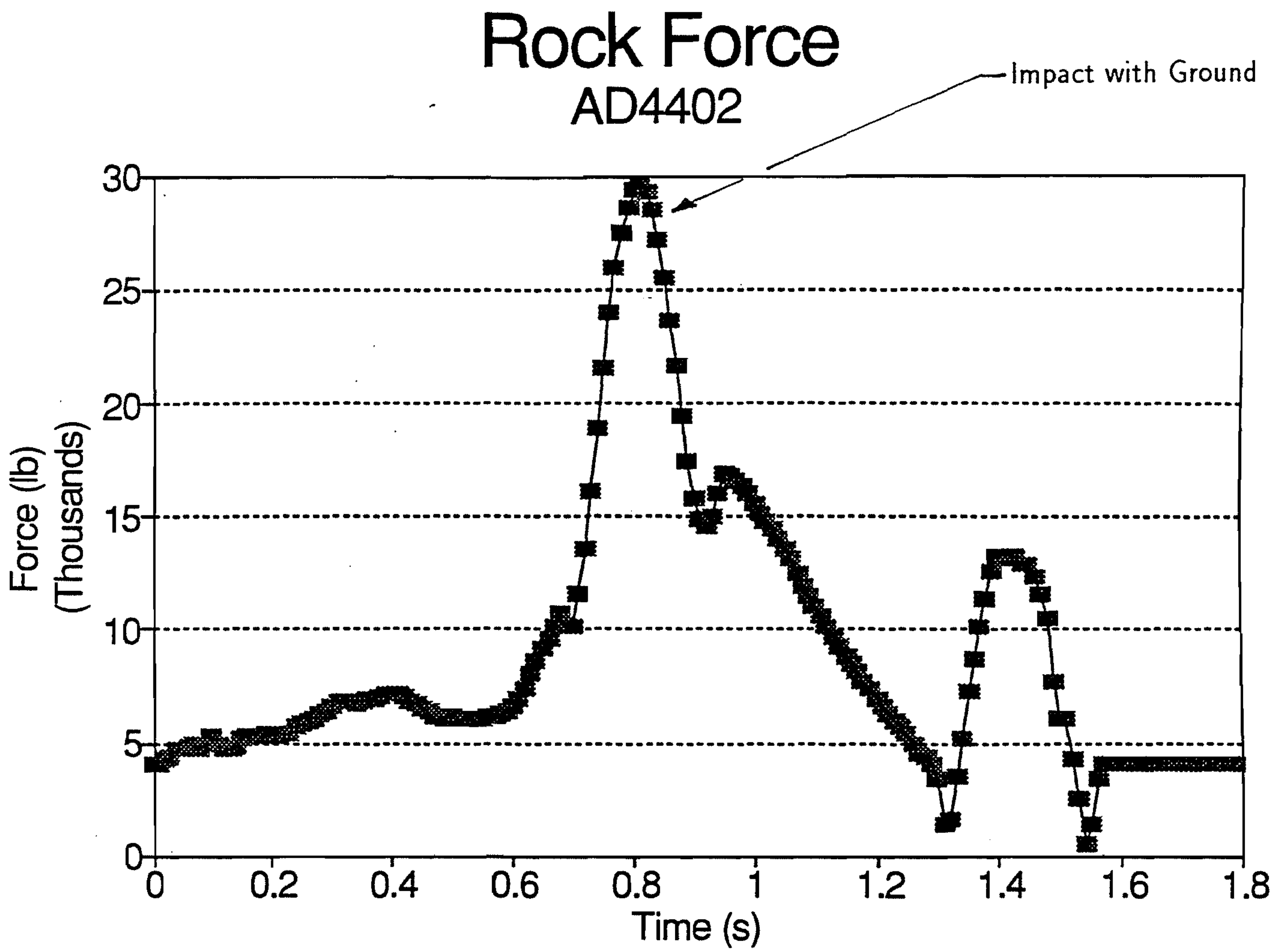


Figure III - 41
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model A.D

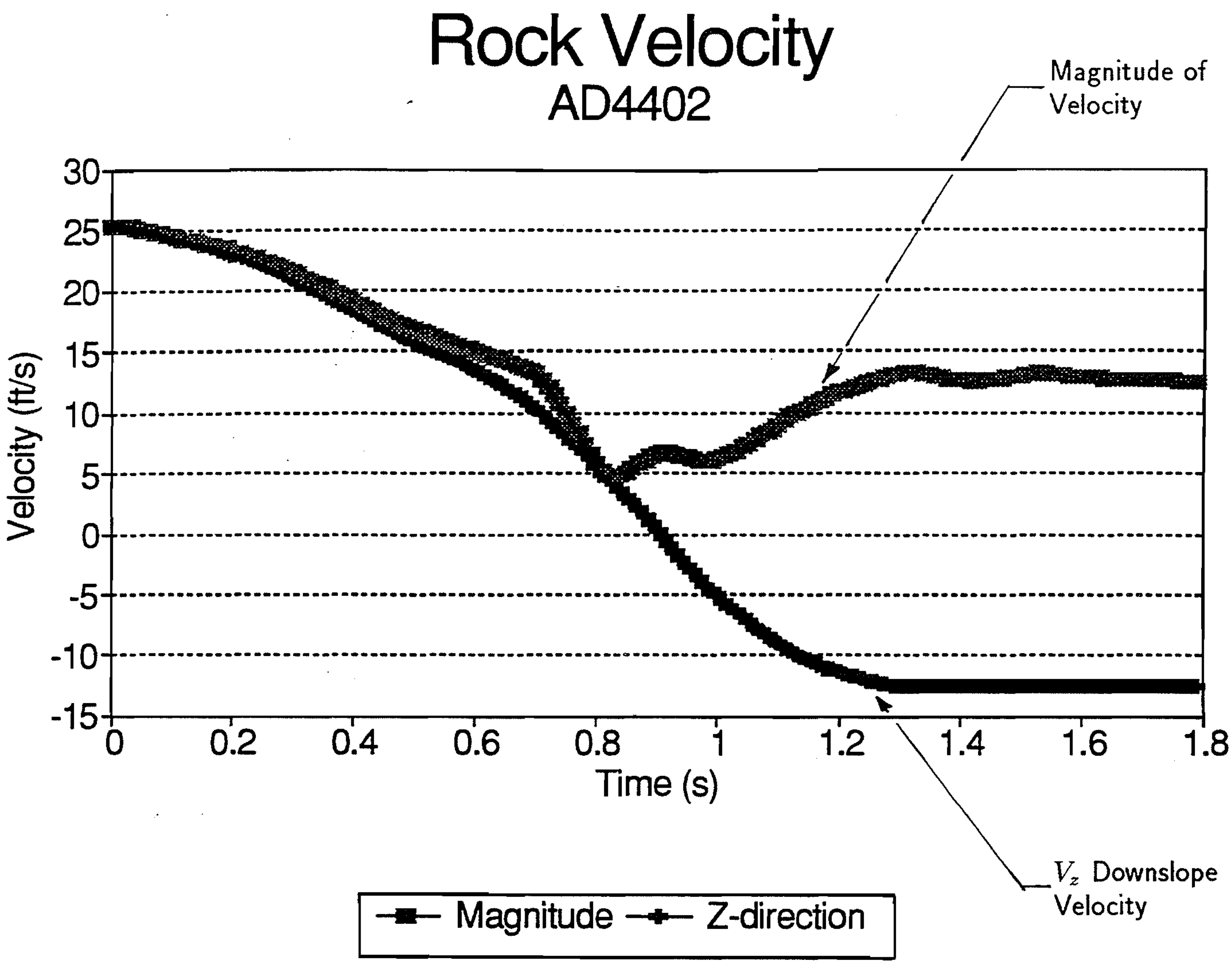


Figure III - 42
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model A.D

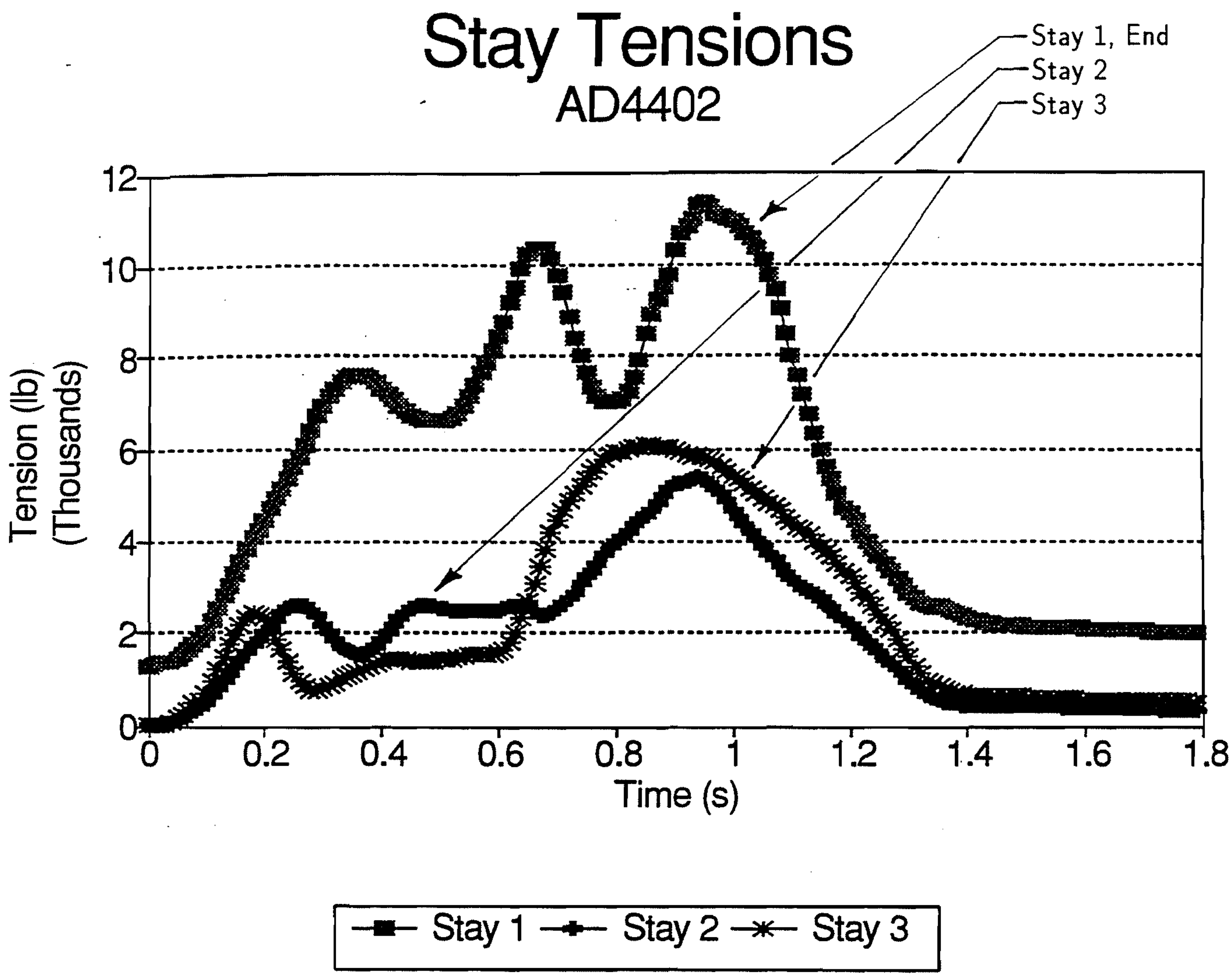


Figure III - 43
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model A.D

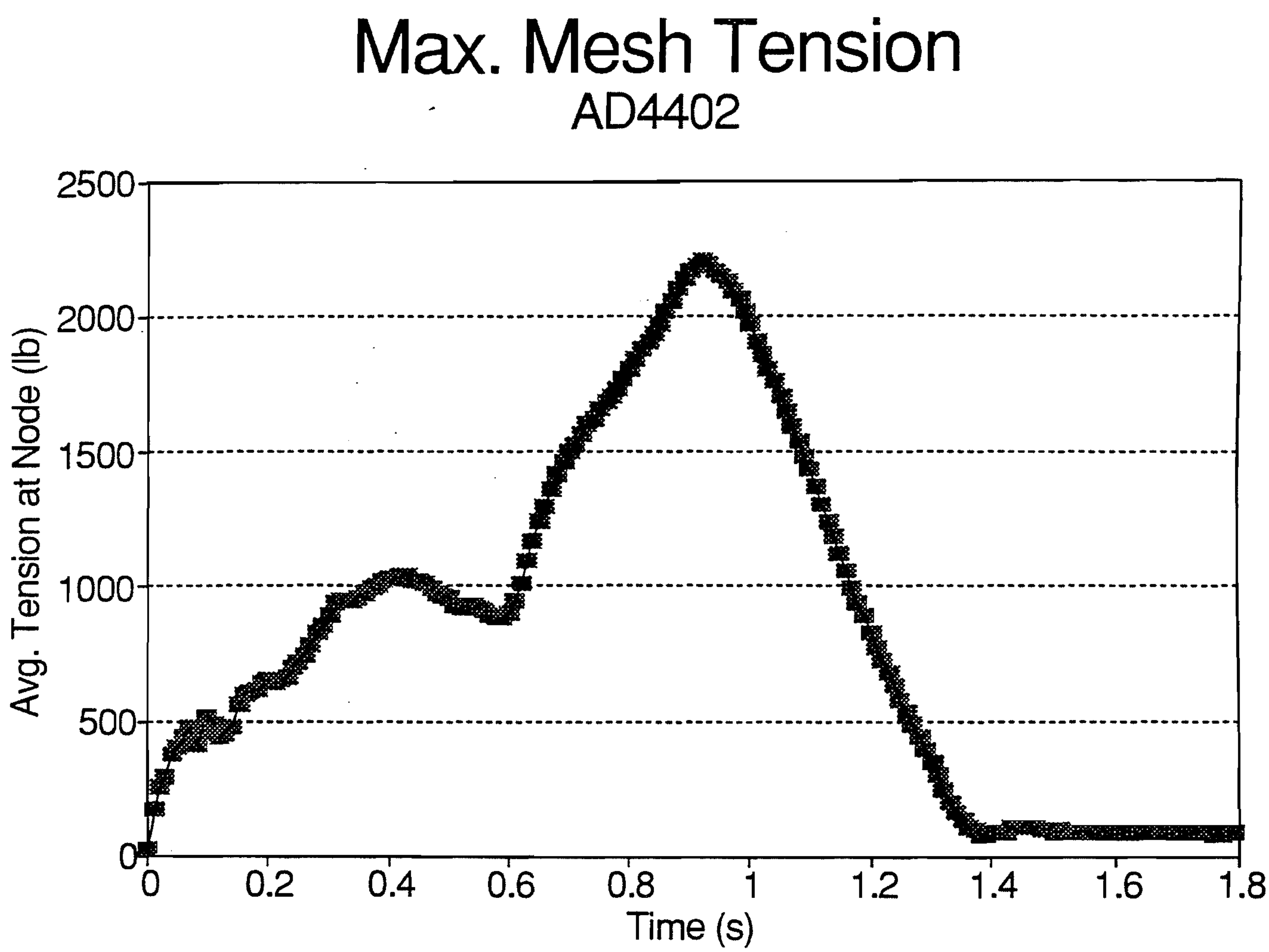


Figure III - 44
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model A.D

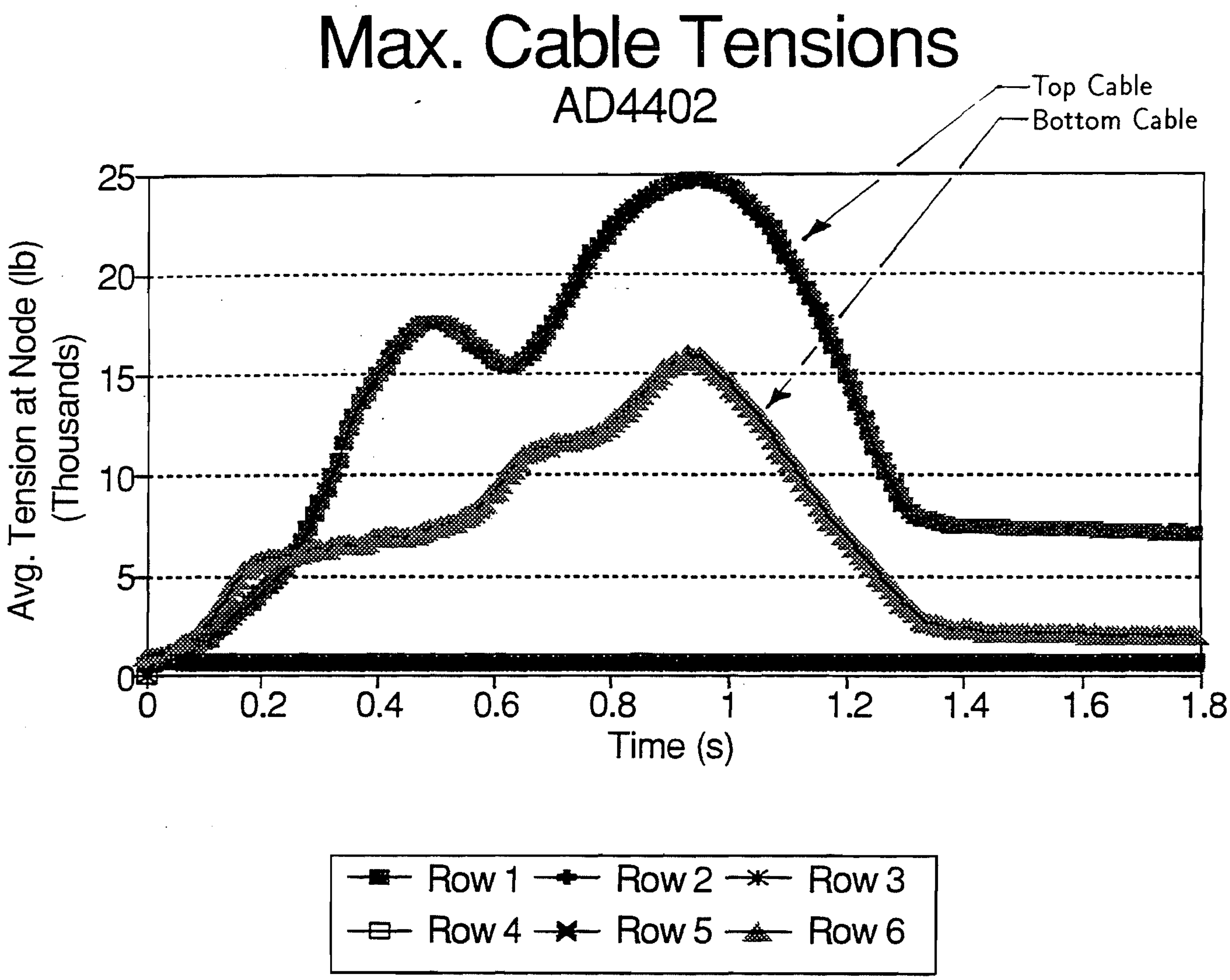
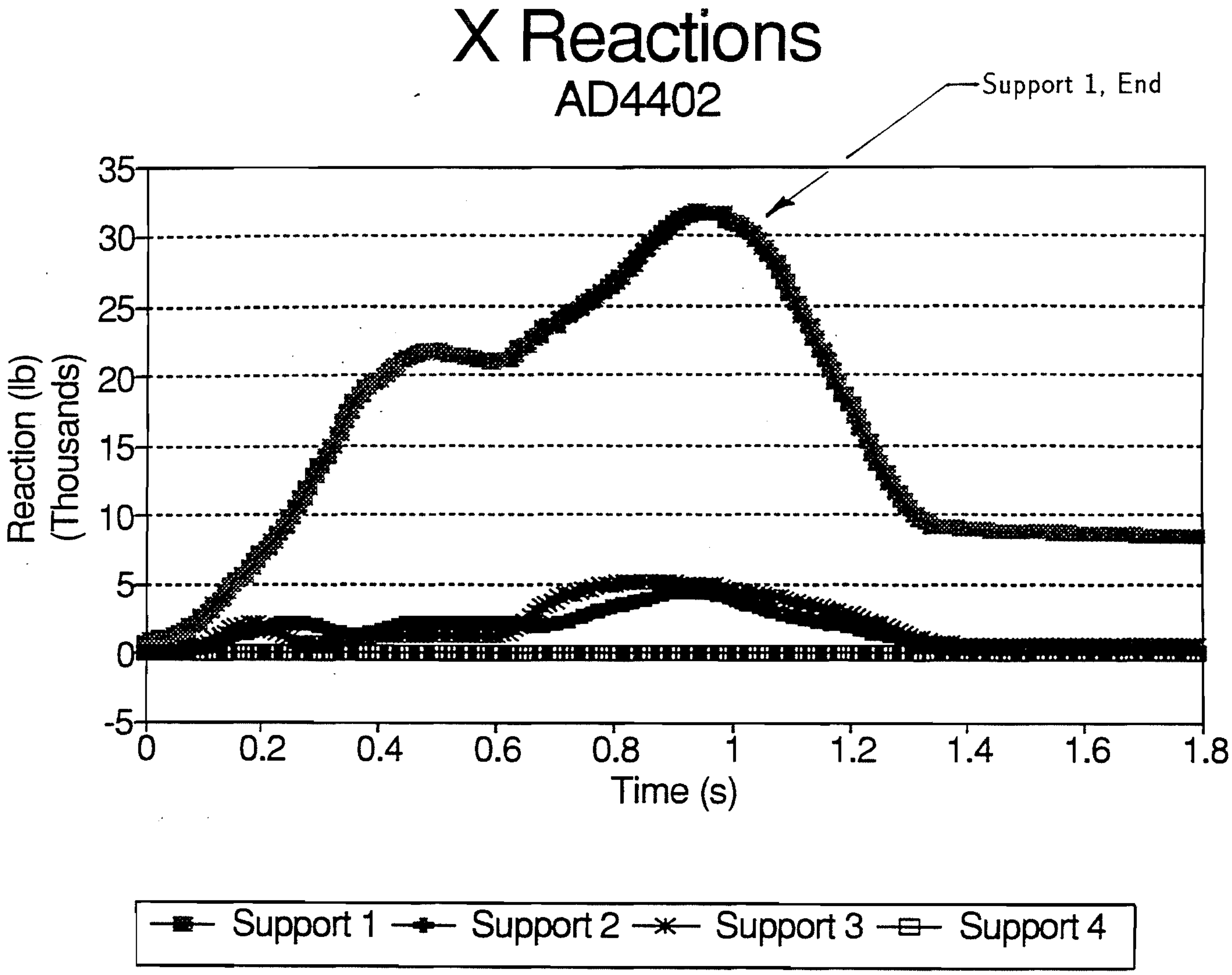
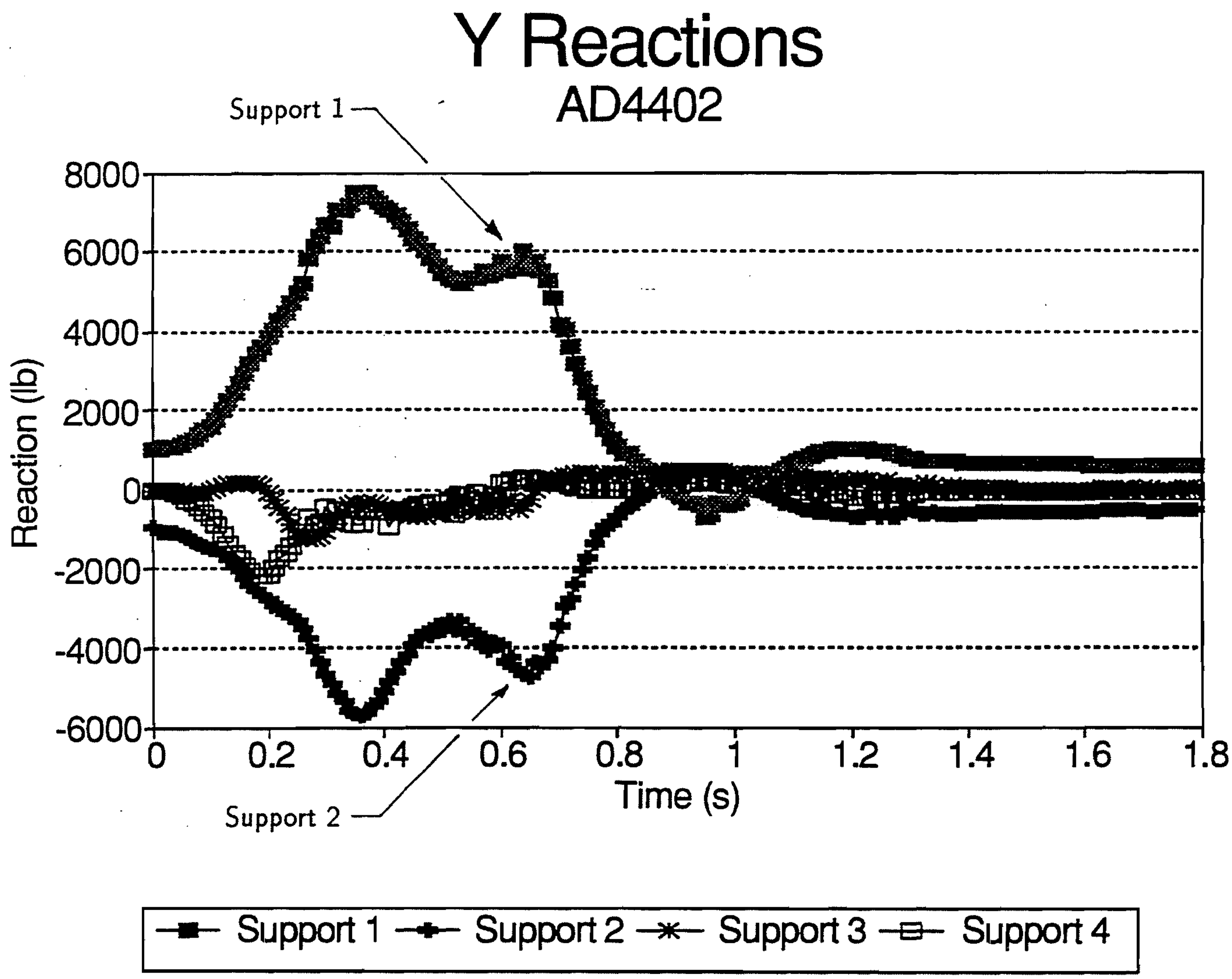


Figure III - 45
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model A.D



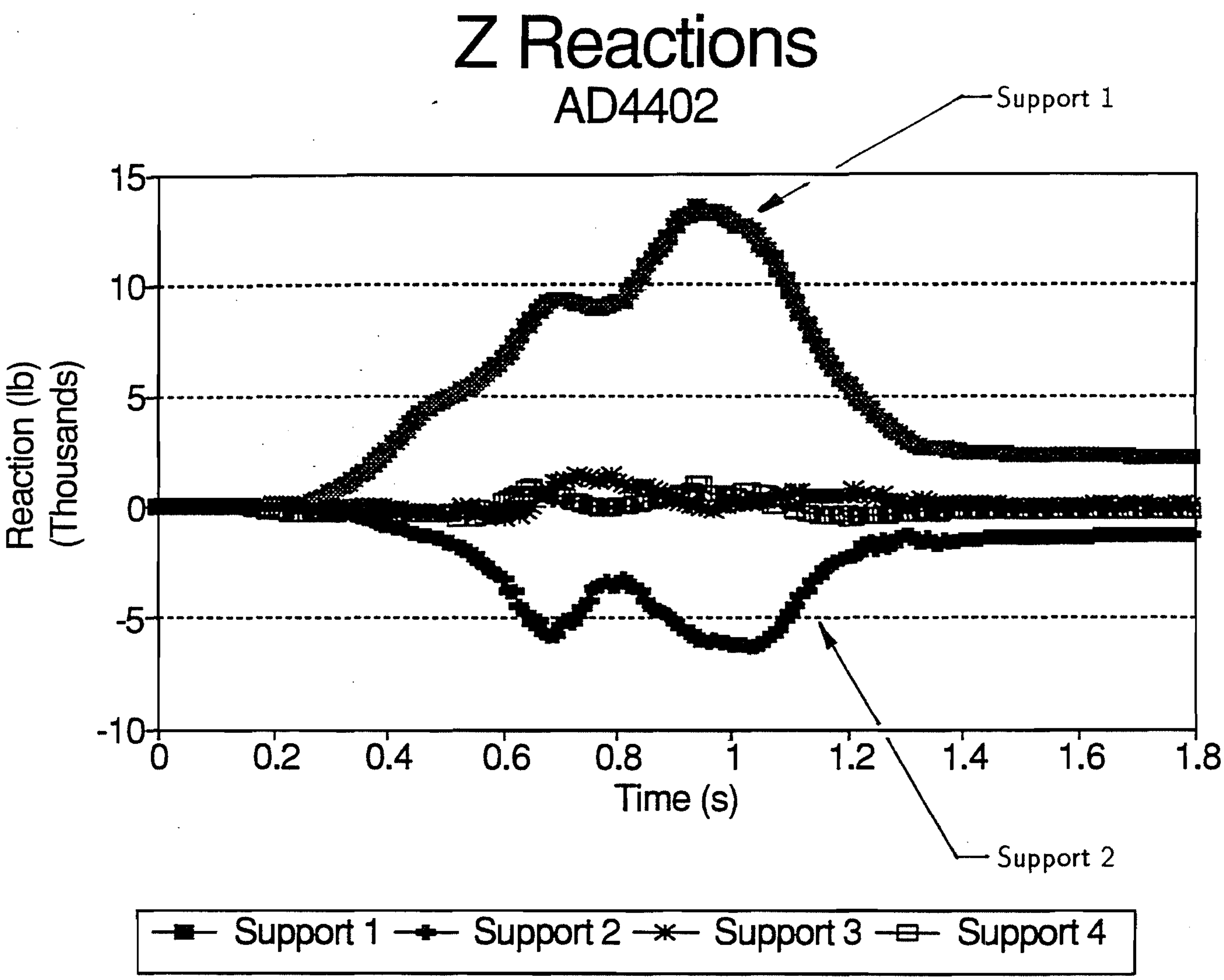
X Reaction, in-plane

Figure III - 46
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model A.D



Y Reaction, Vertical

Figure III - 47
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model A.D



Z Reaction, Downslope

Figure III - 48
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model A.D

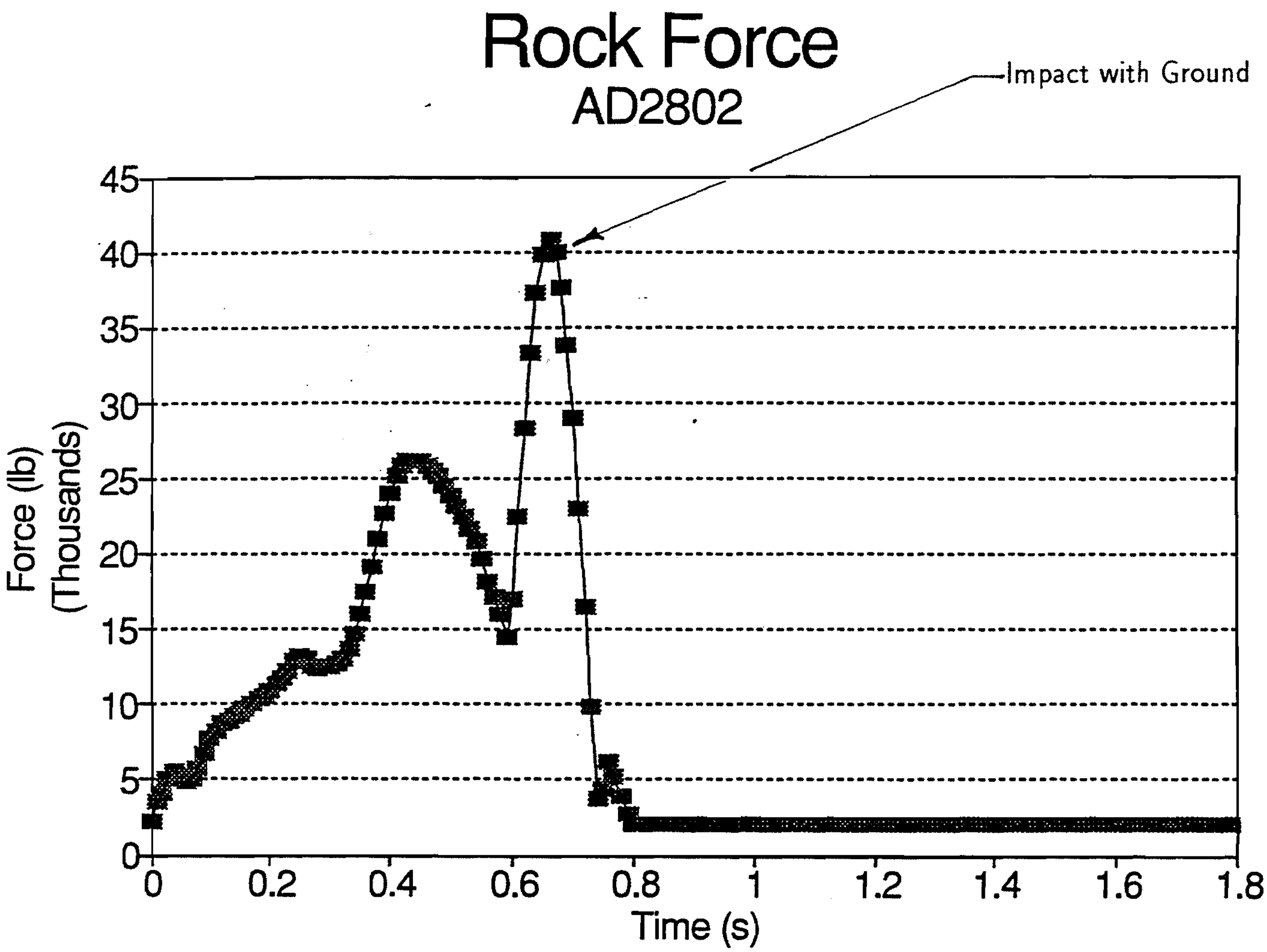


Figure III - 49
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model A.D

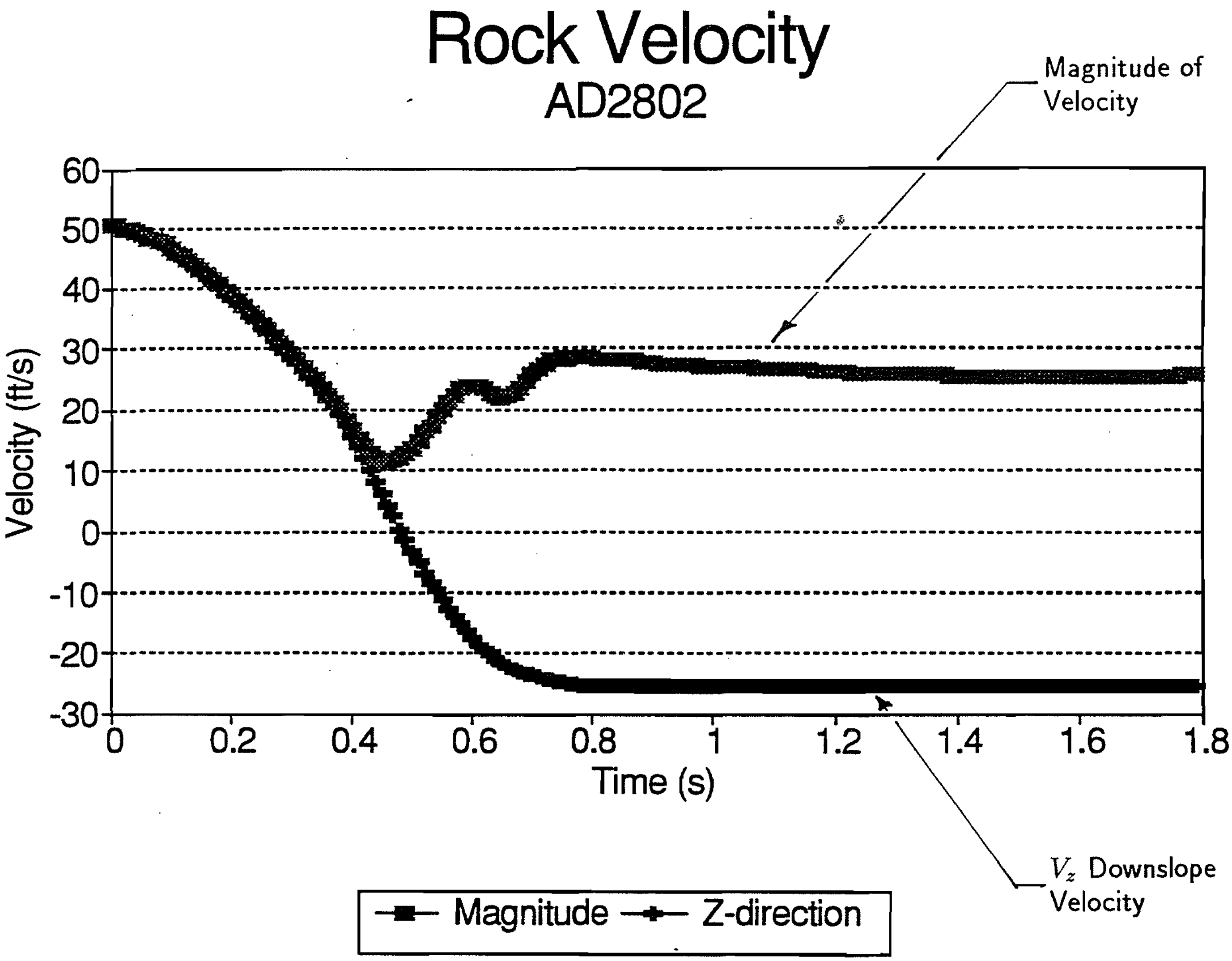


Figure III - 50
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model A.D

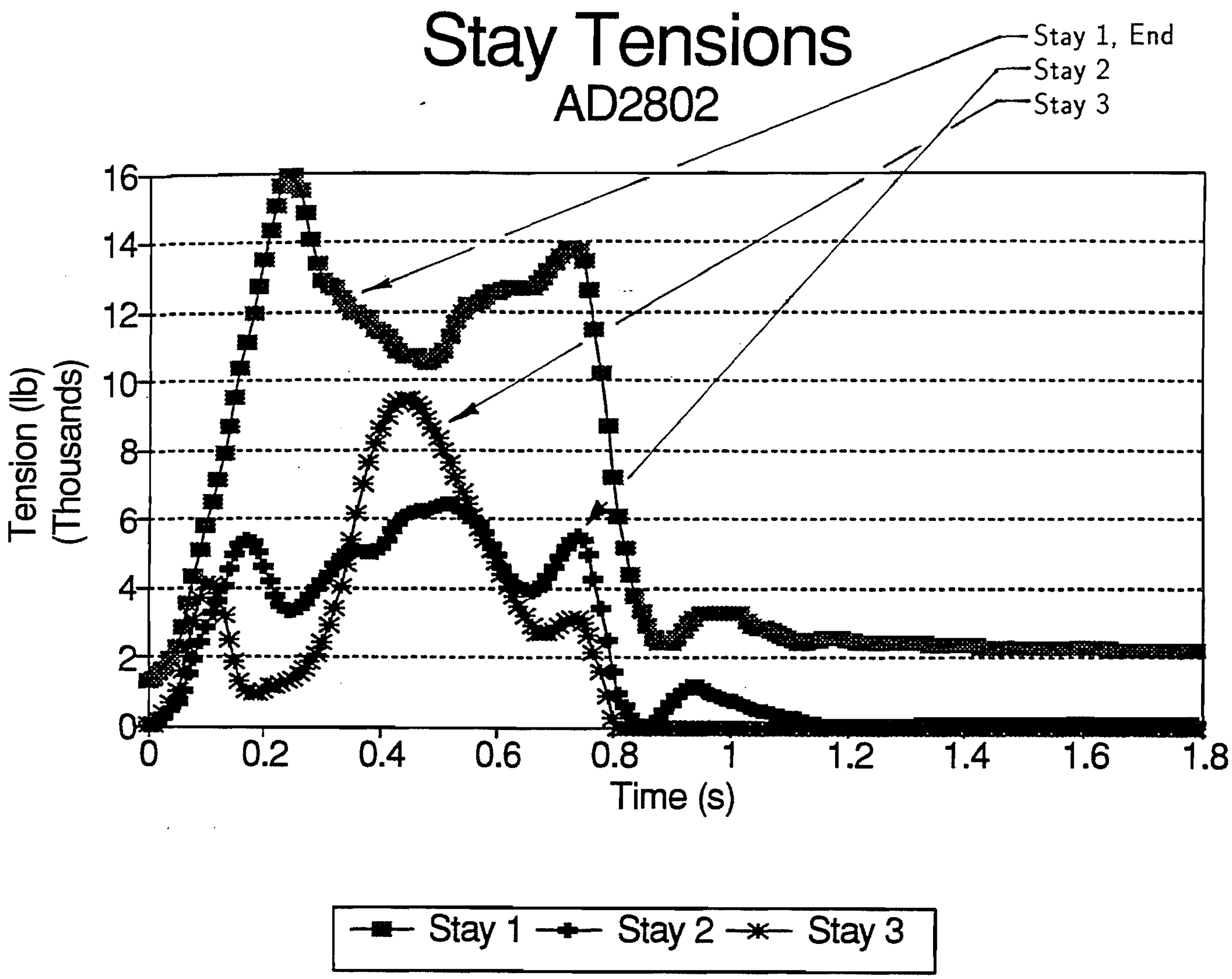


Figure III - 51
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model A.D

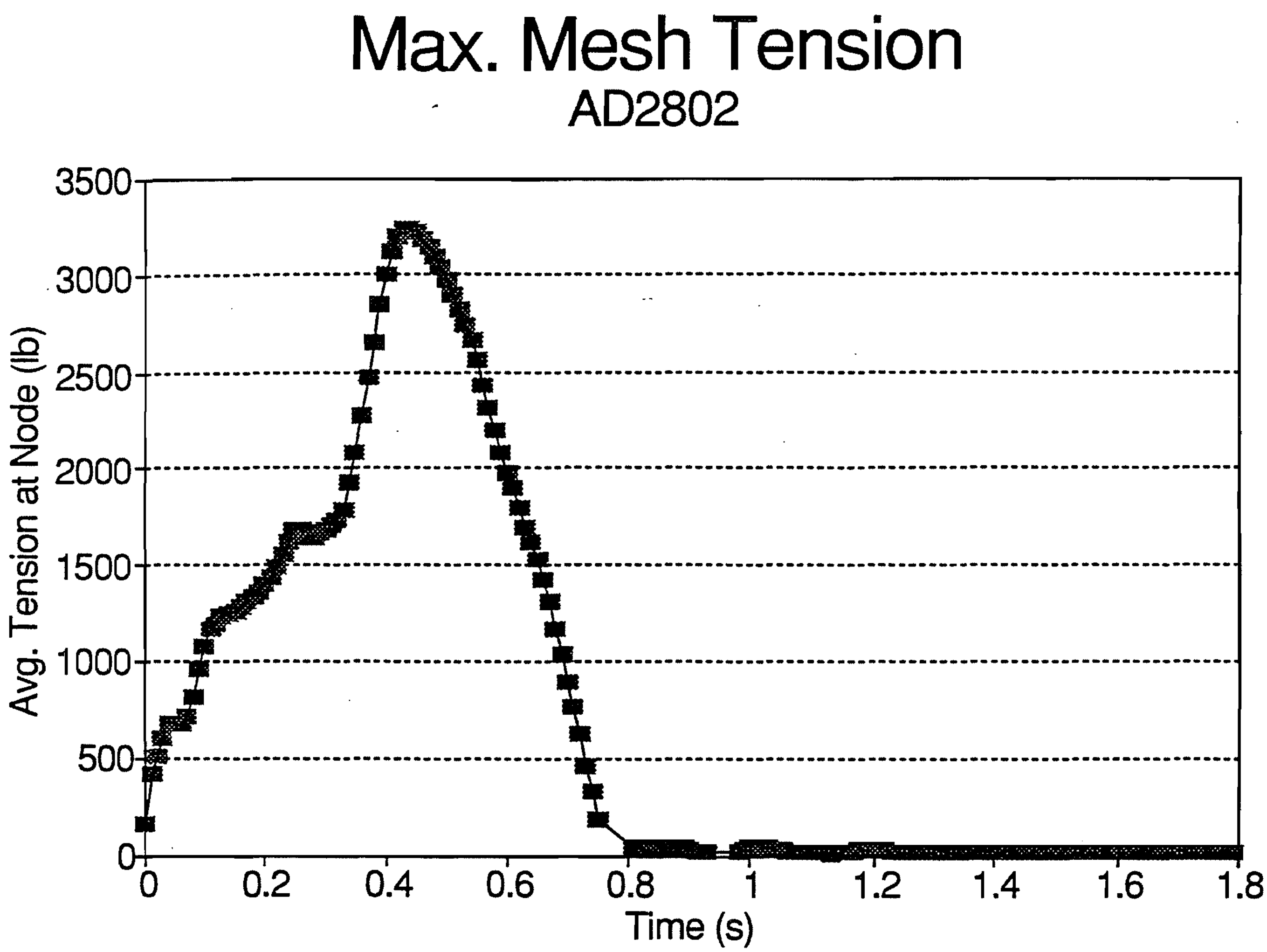


Figure III - 52
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model A.D

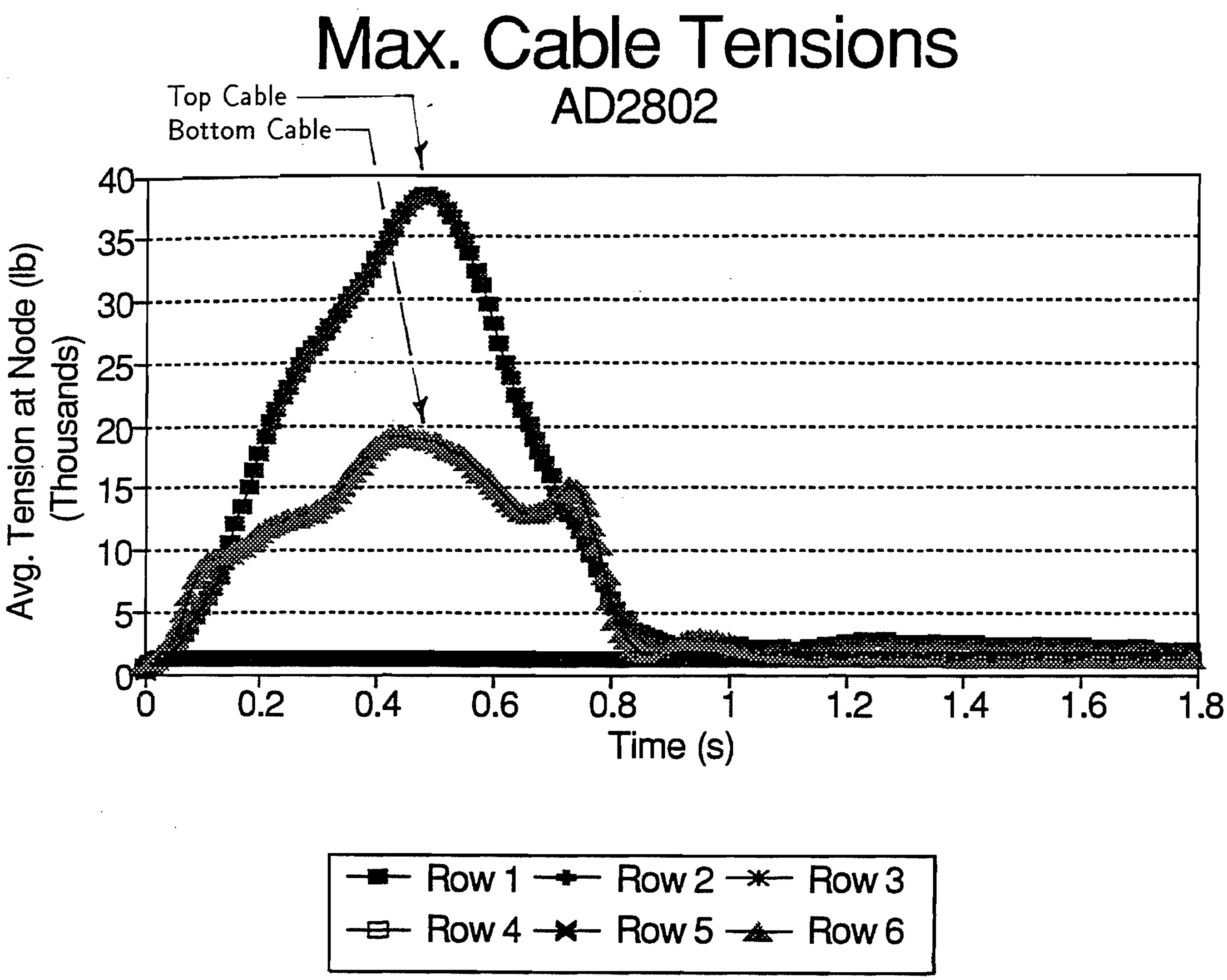
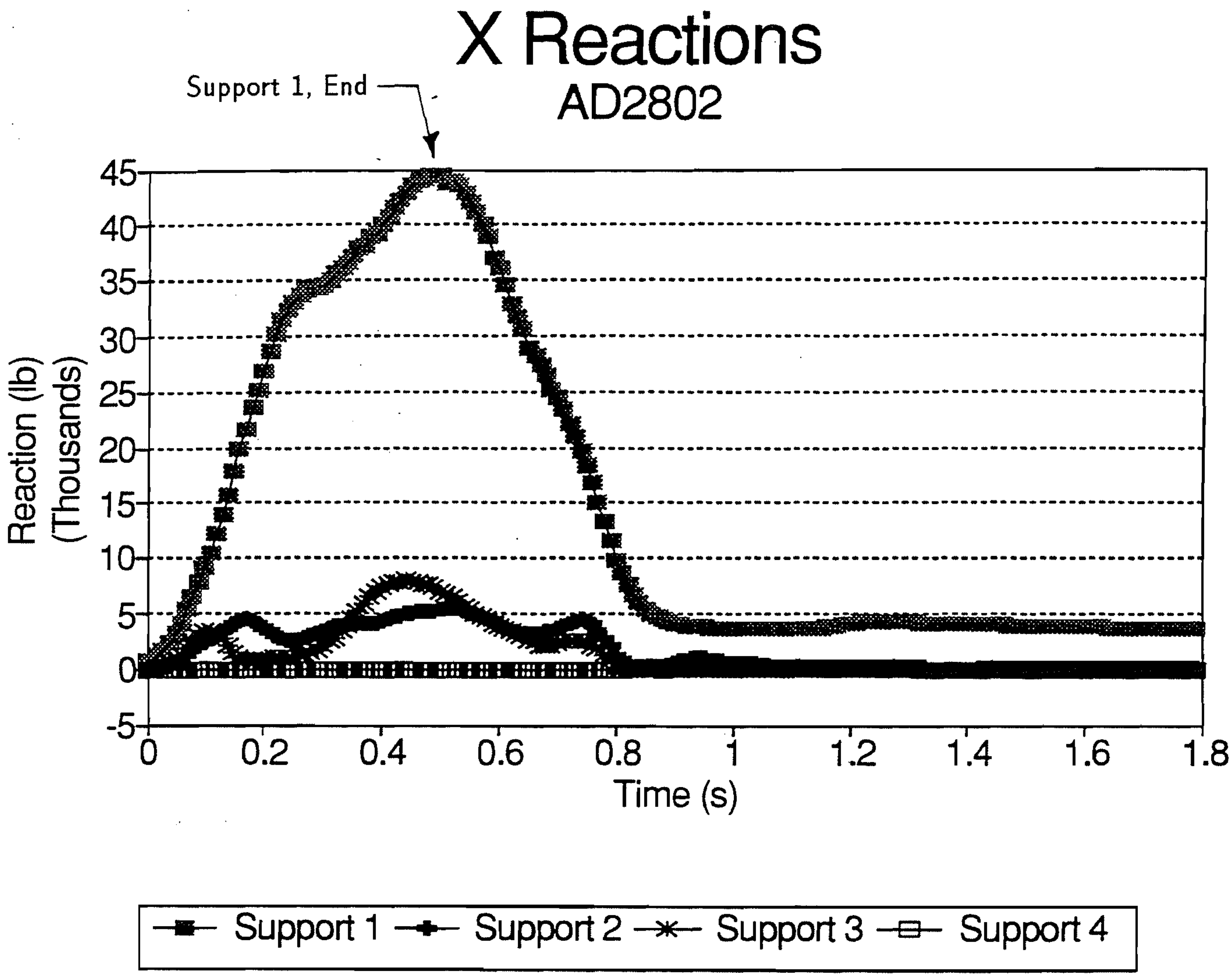
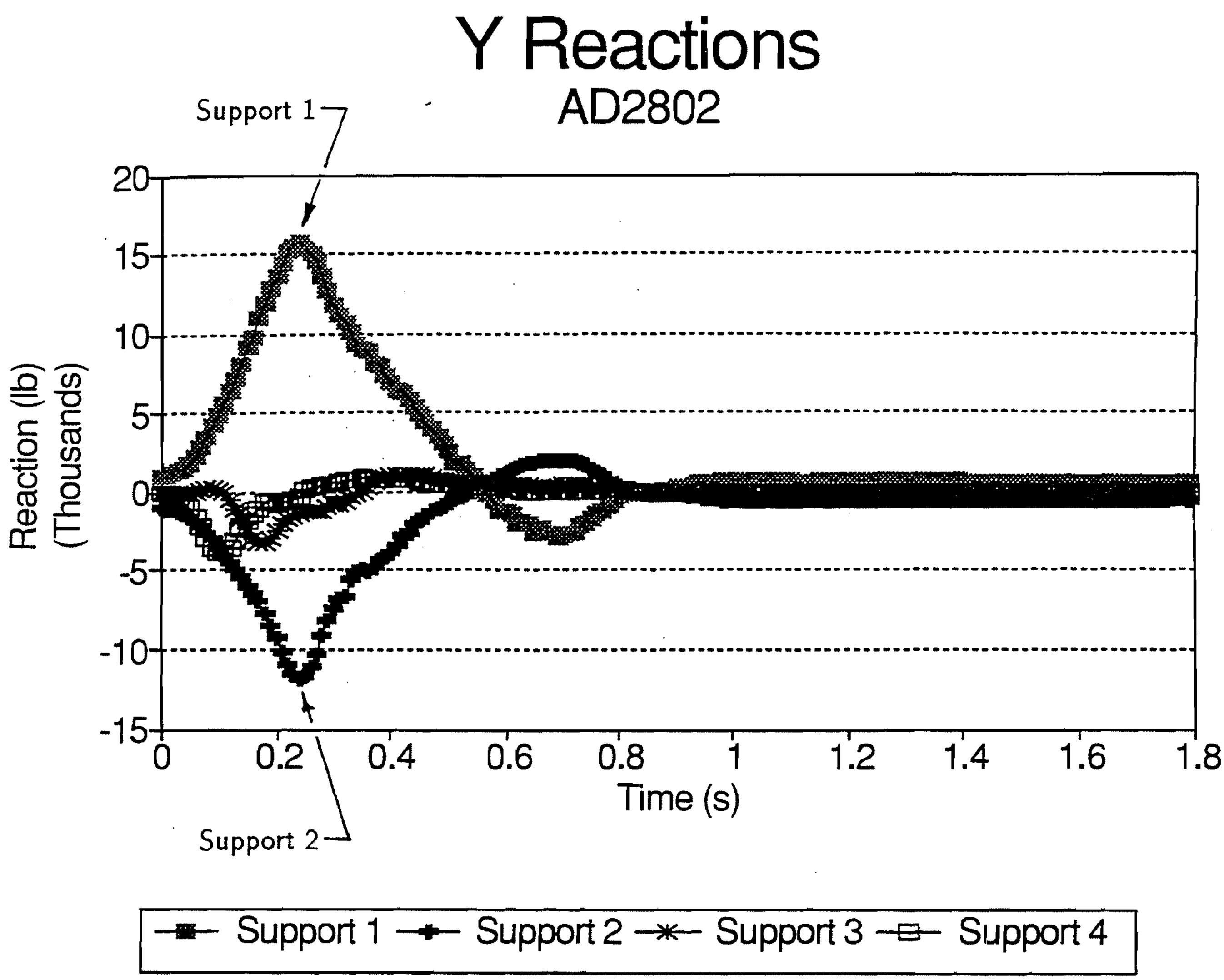


Figure III - 53
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model A.D



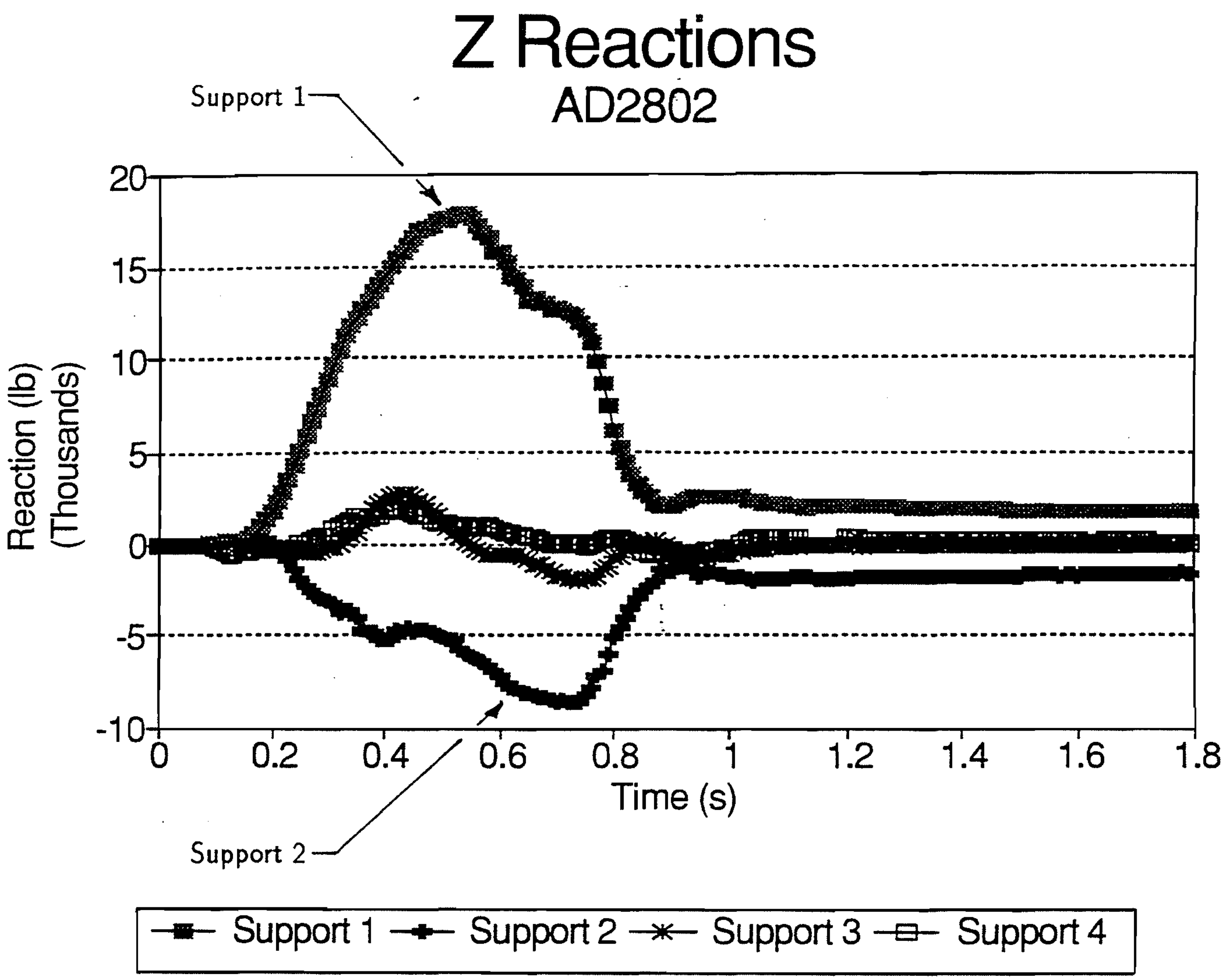
X Reaction, in-plane

Figure III - 54
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model A.D



Y Reaction, Vertical

Figure III - 55
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model A.D



Z Reaction, Downslope

Figure III - 56
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model A.D

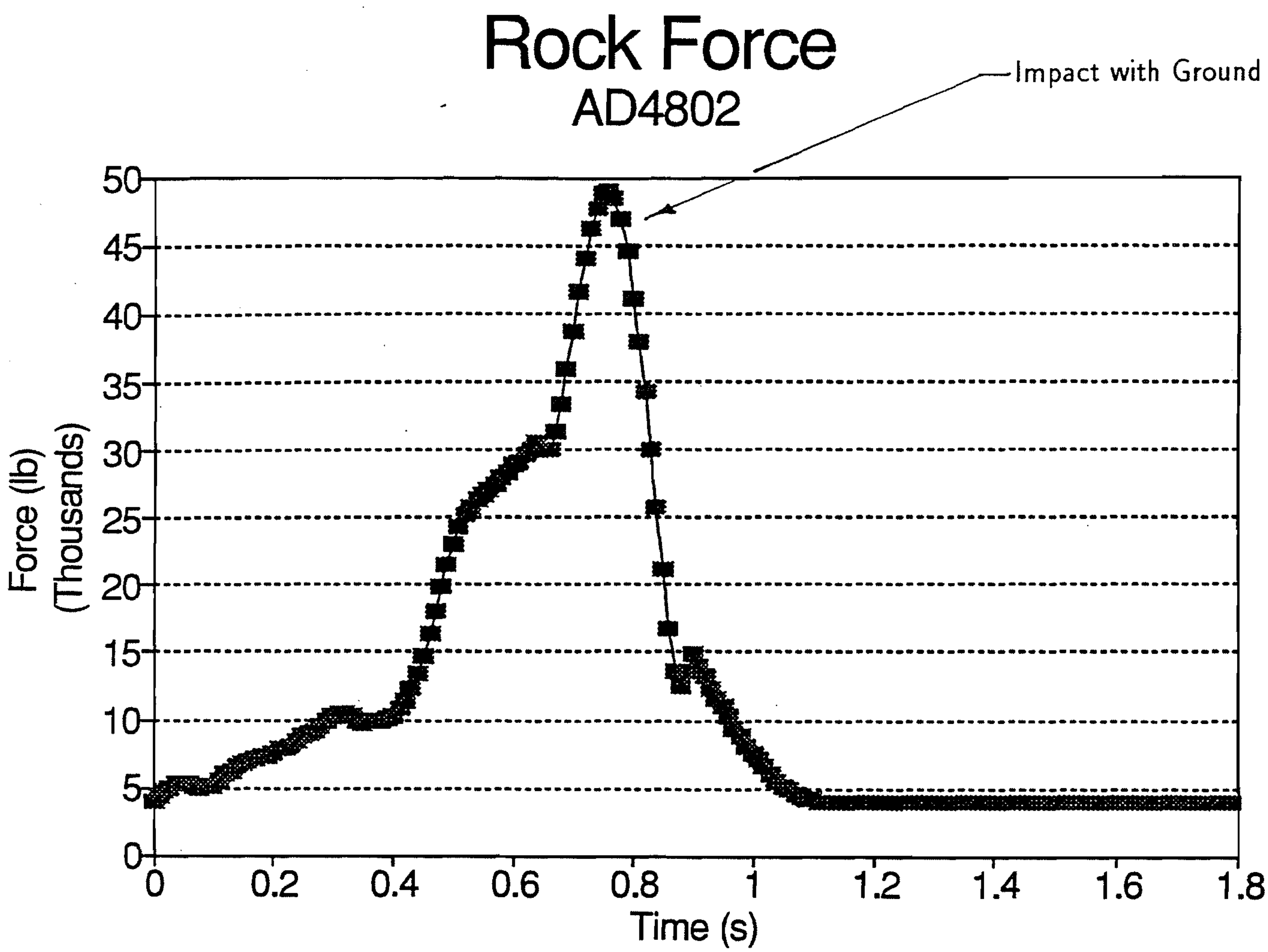


Figure III - 57
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model A.D

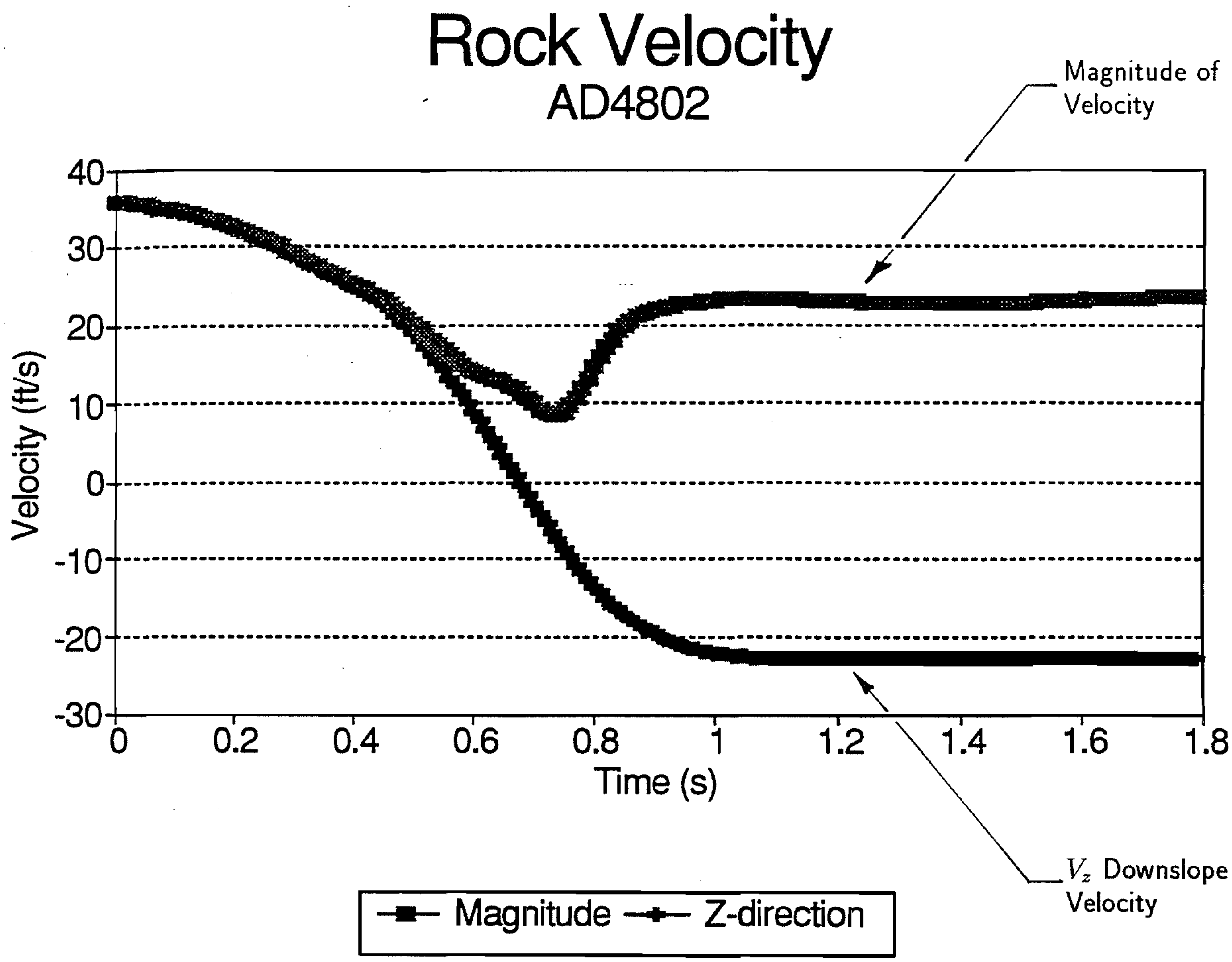


Figure III - 58
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model A.D

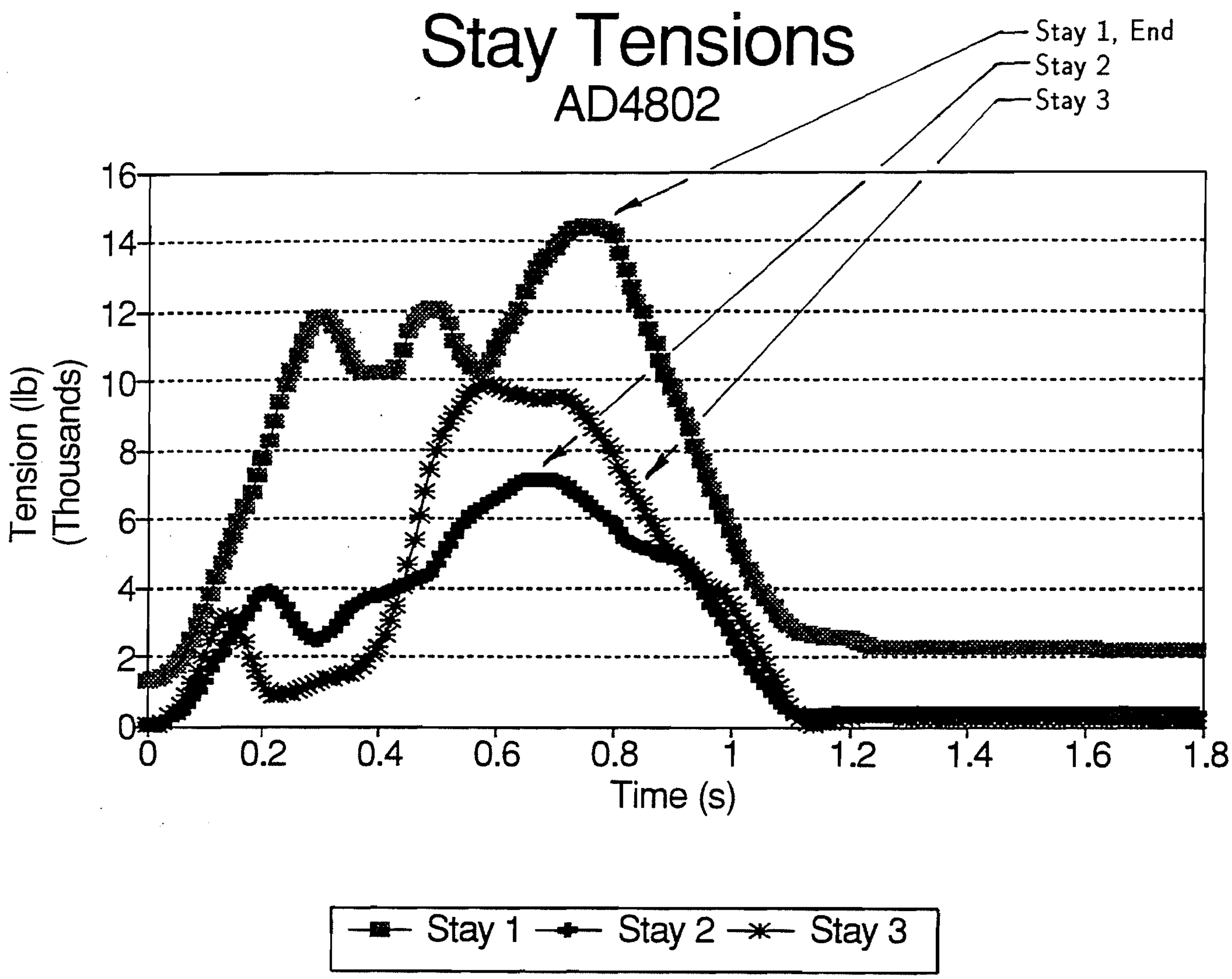


Figure III - 59
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model A.D

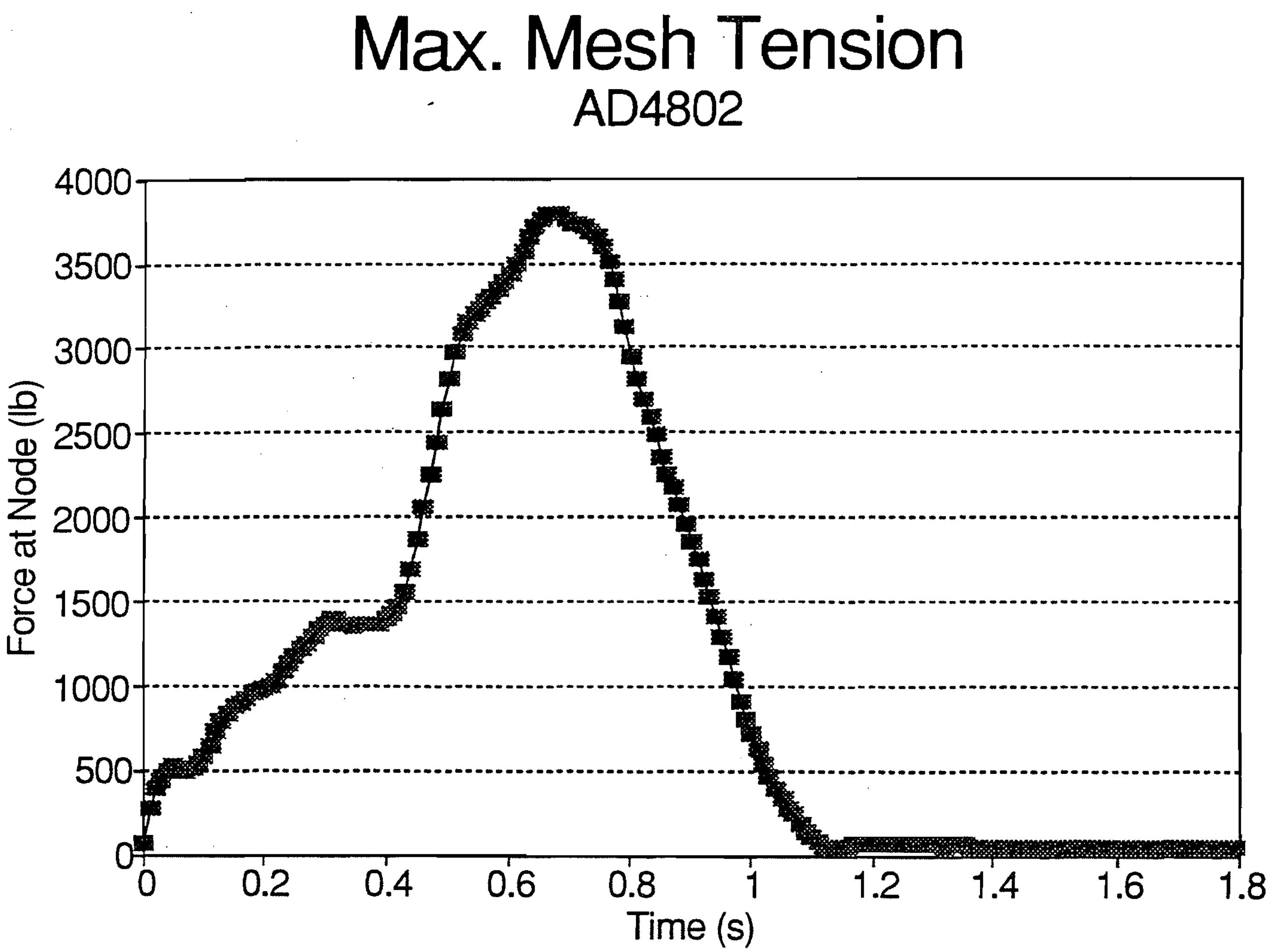


Figure III - 60
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model A.D

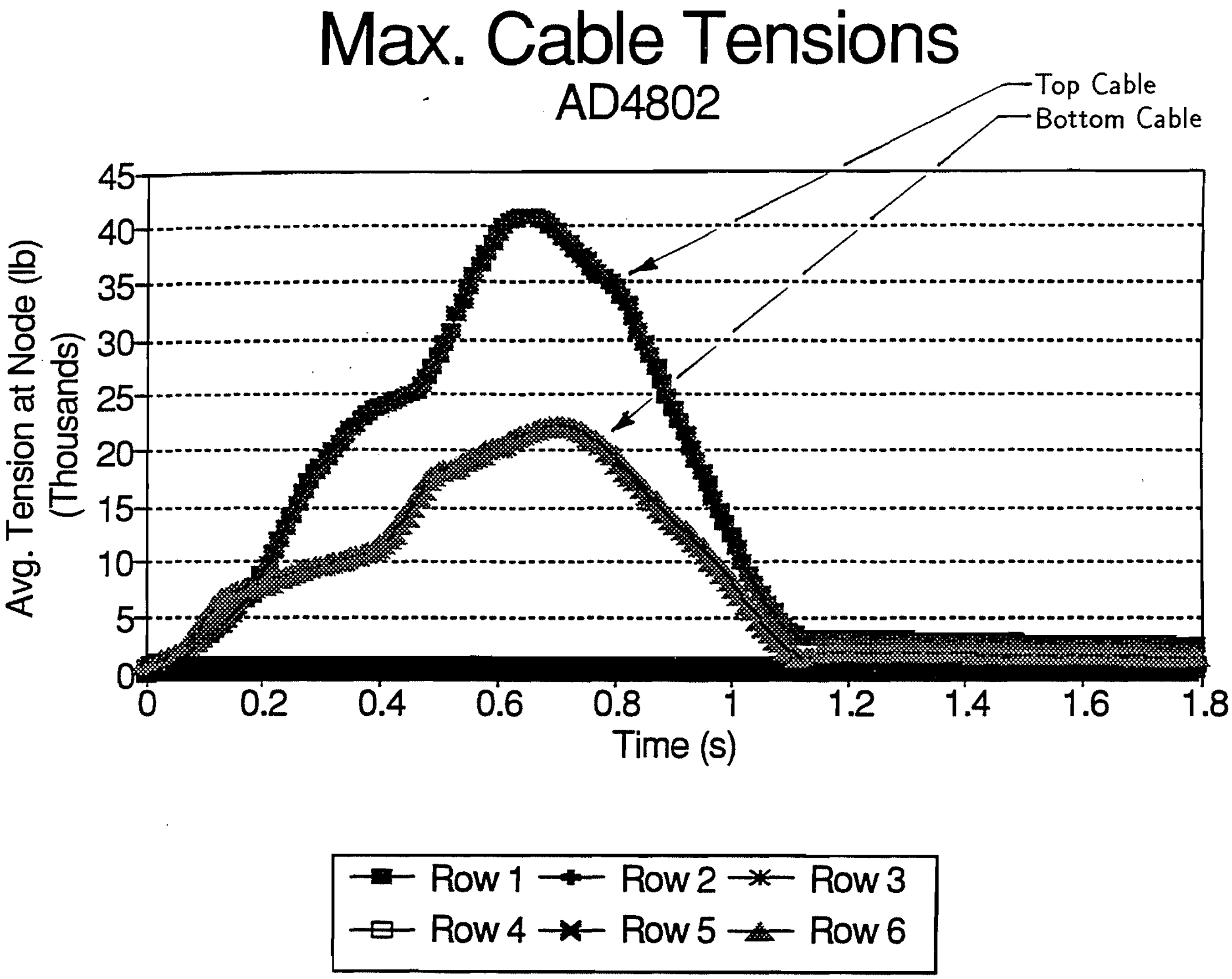
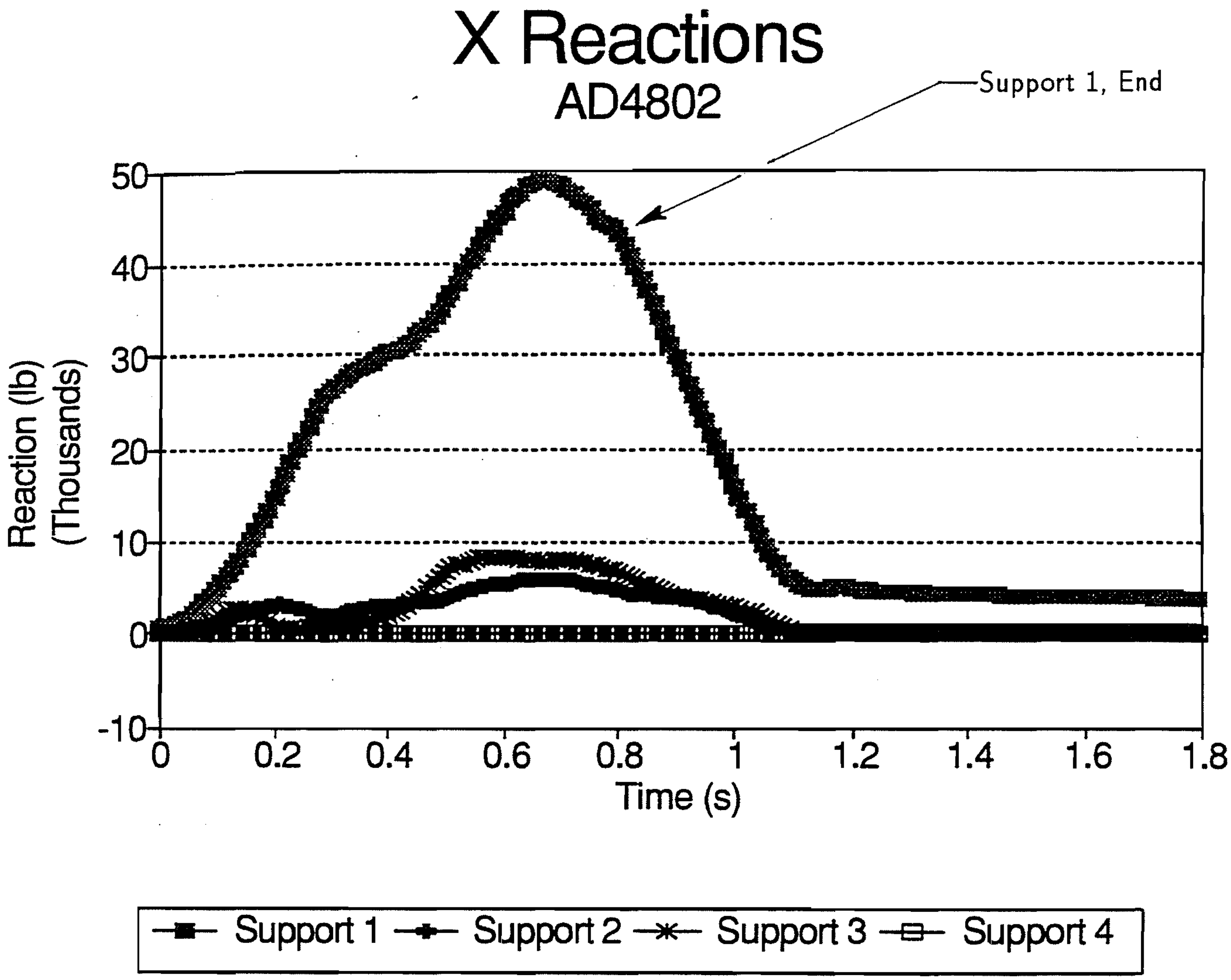
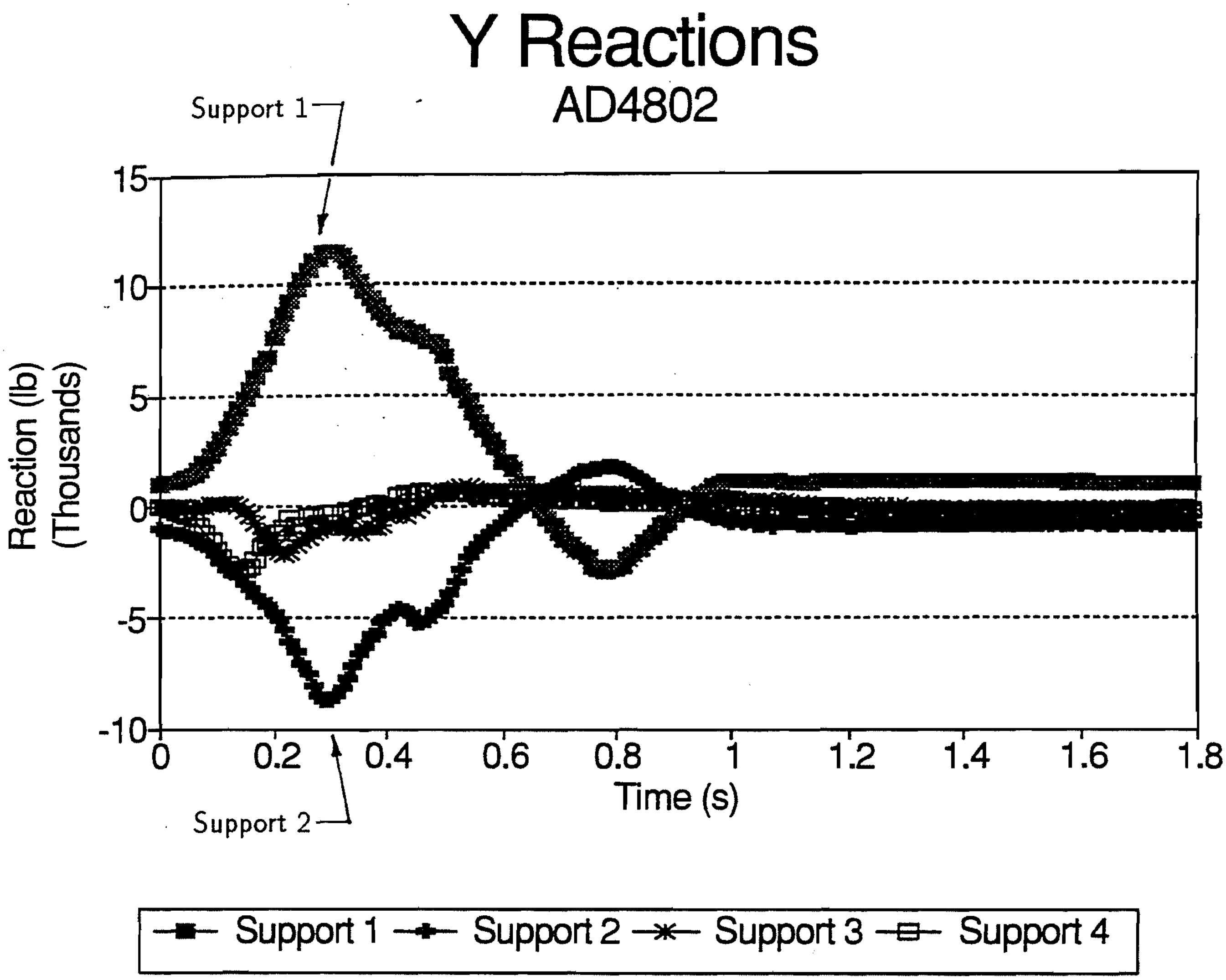


Figure III - 61
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model A.D



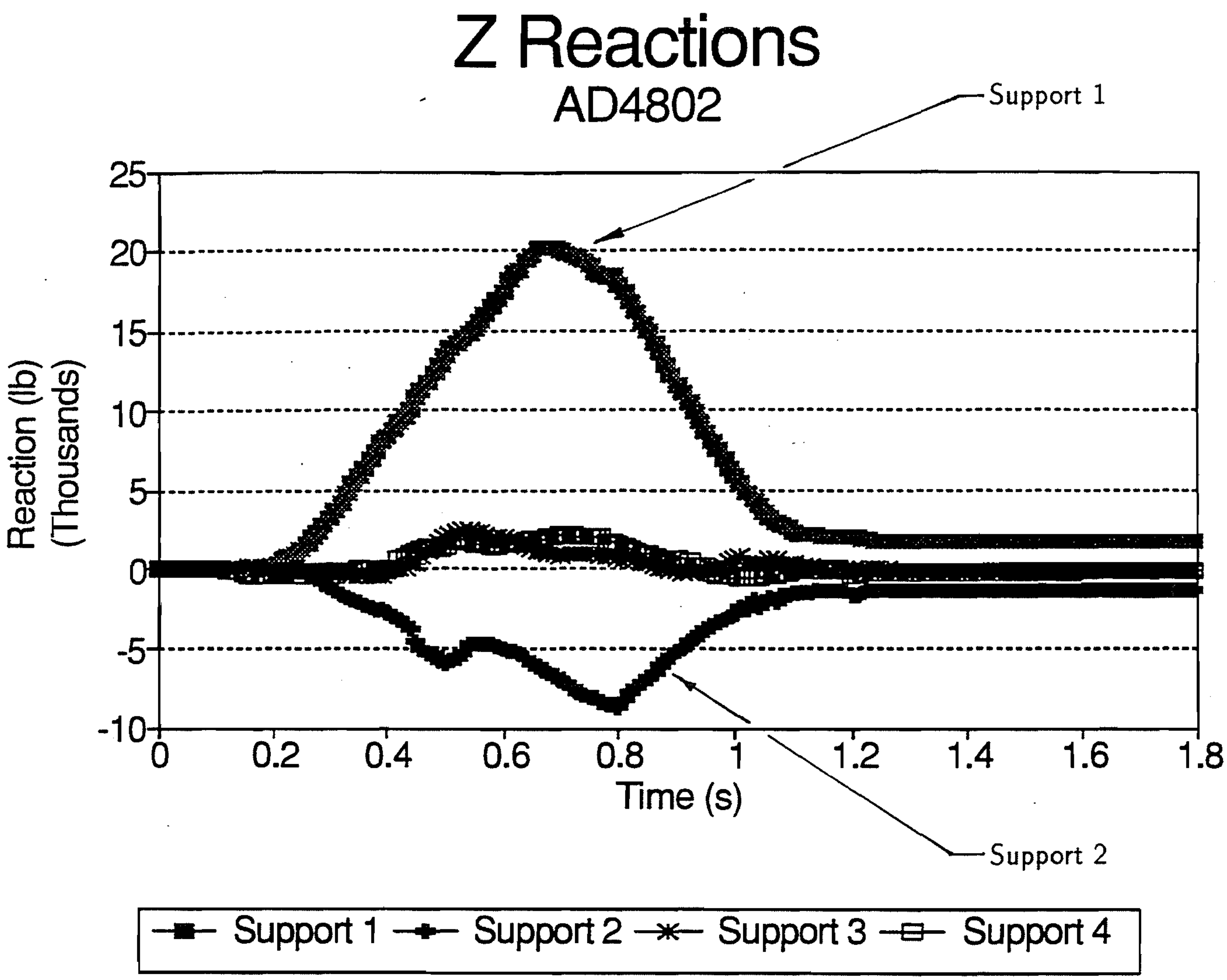
X Reaction, in-plane

Figure III - 62
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model A.D



Y Reaction, Vertical

Figure III - 63
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model A.D



Z Reaction, Downslope

Figure III - 64
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model A.D

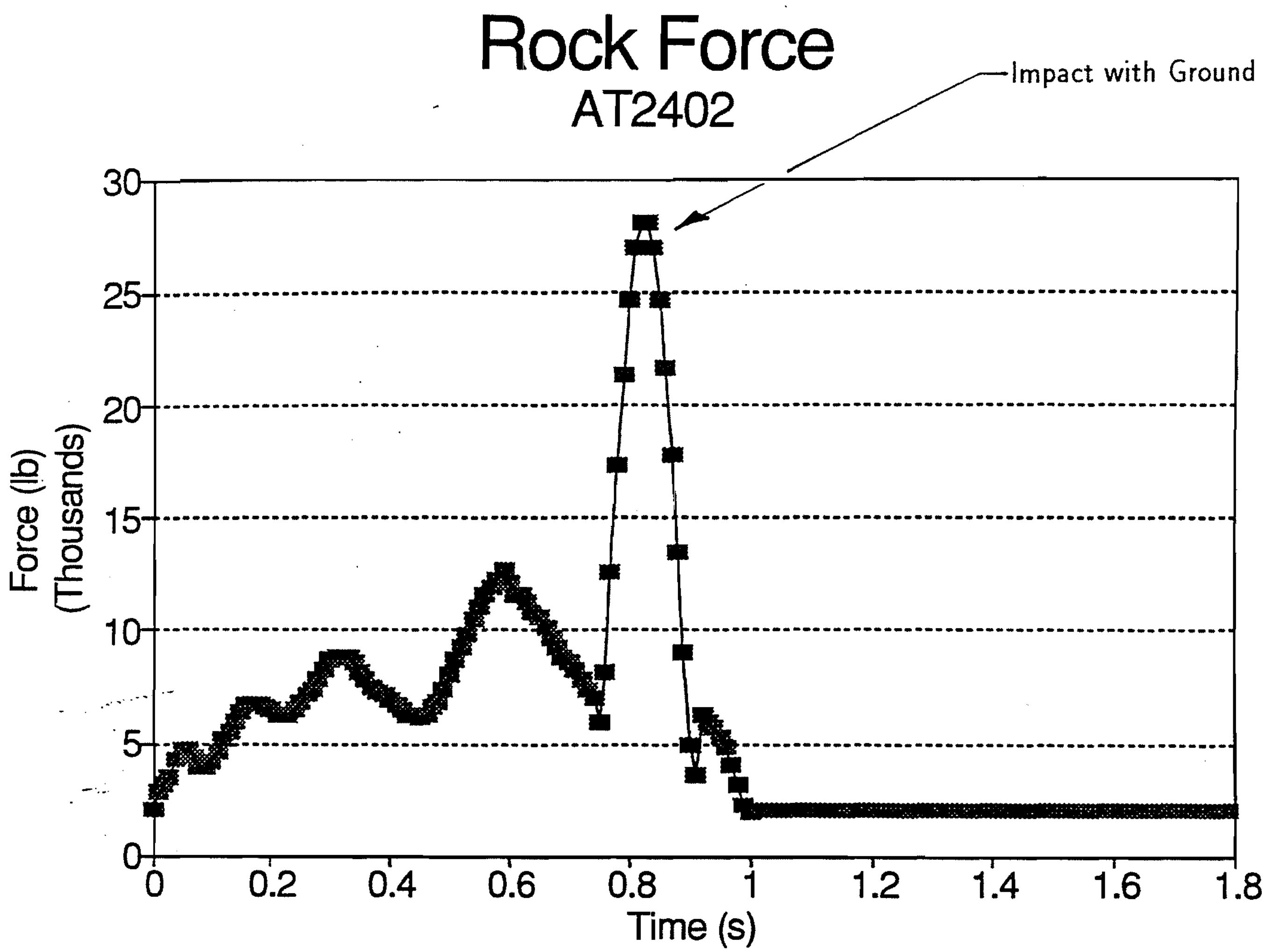


Figure III - 65
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model A.T

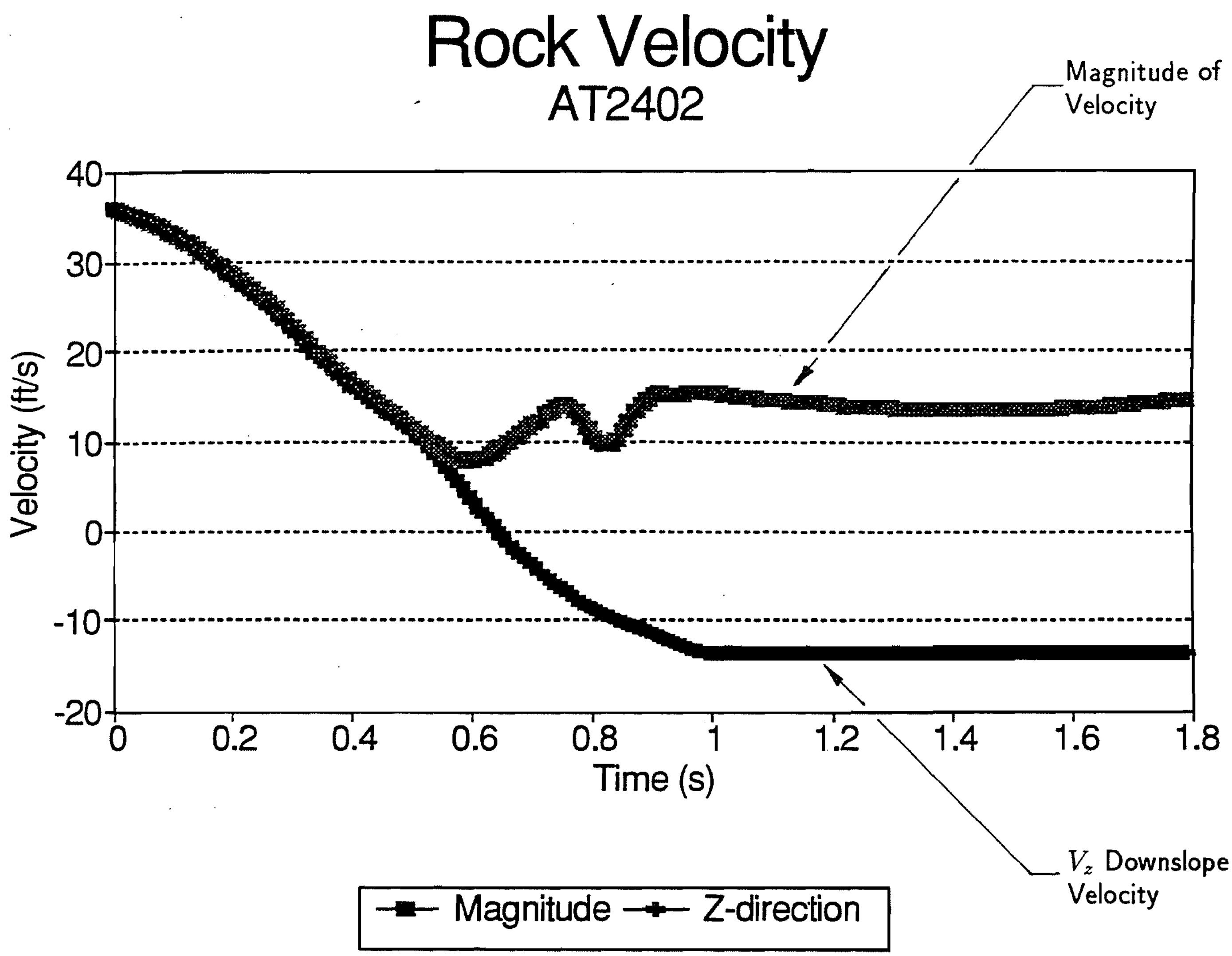


Figure III - 66
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model A.T

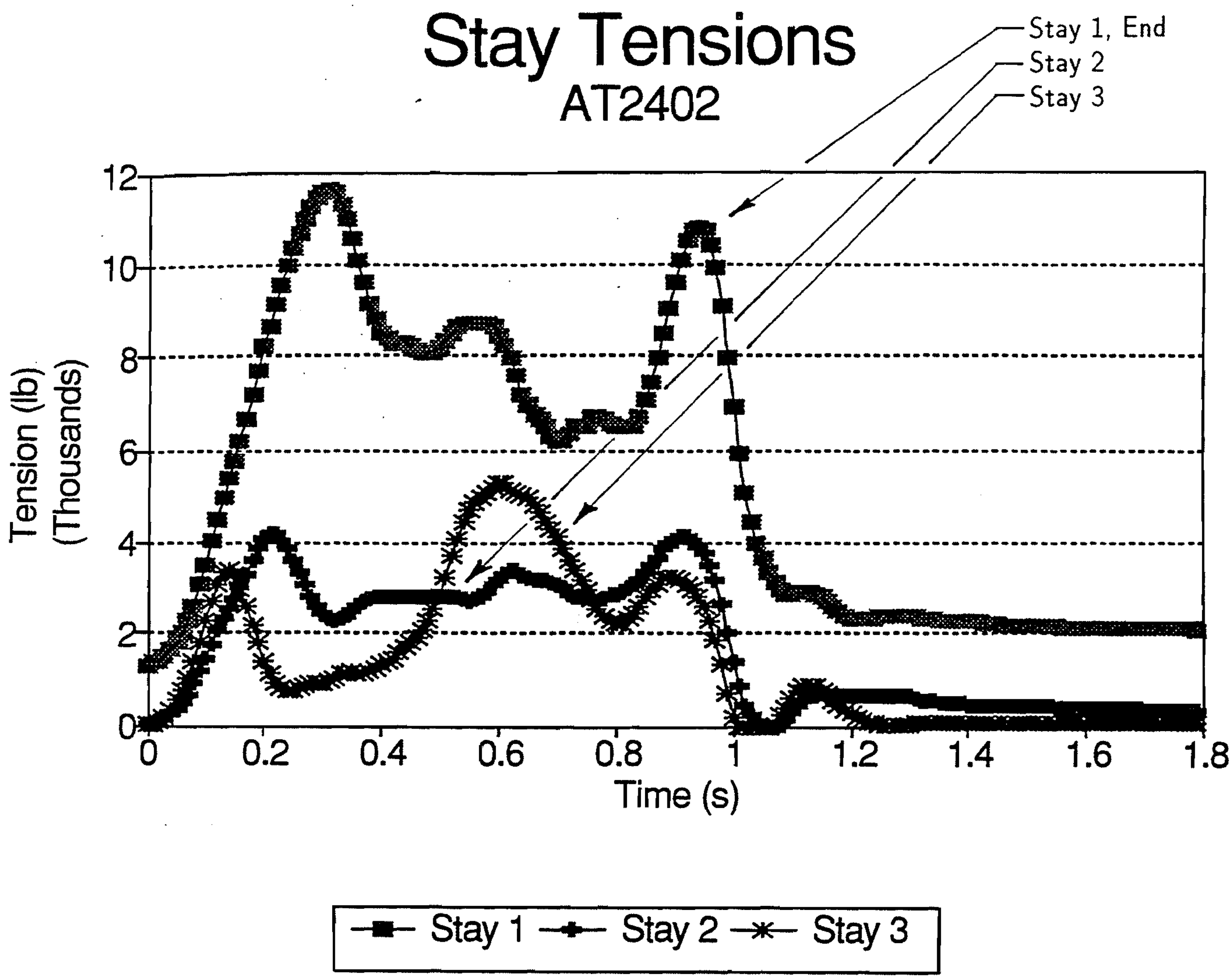


Figure III - 67
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model A.T

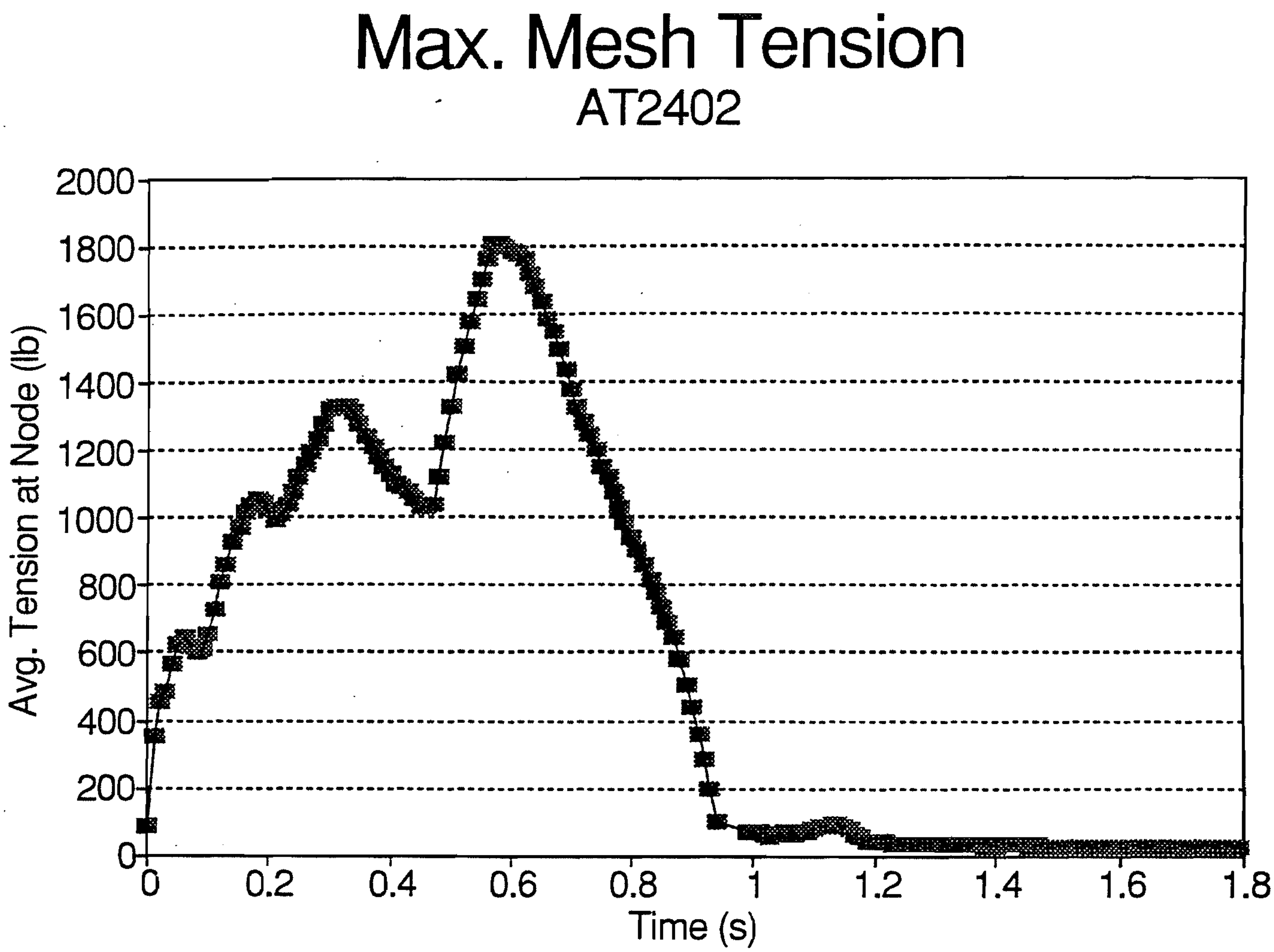


Figure III - 68
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model A.T

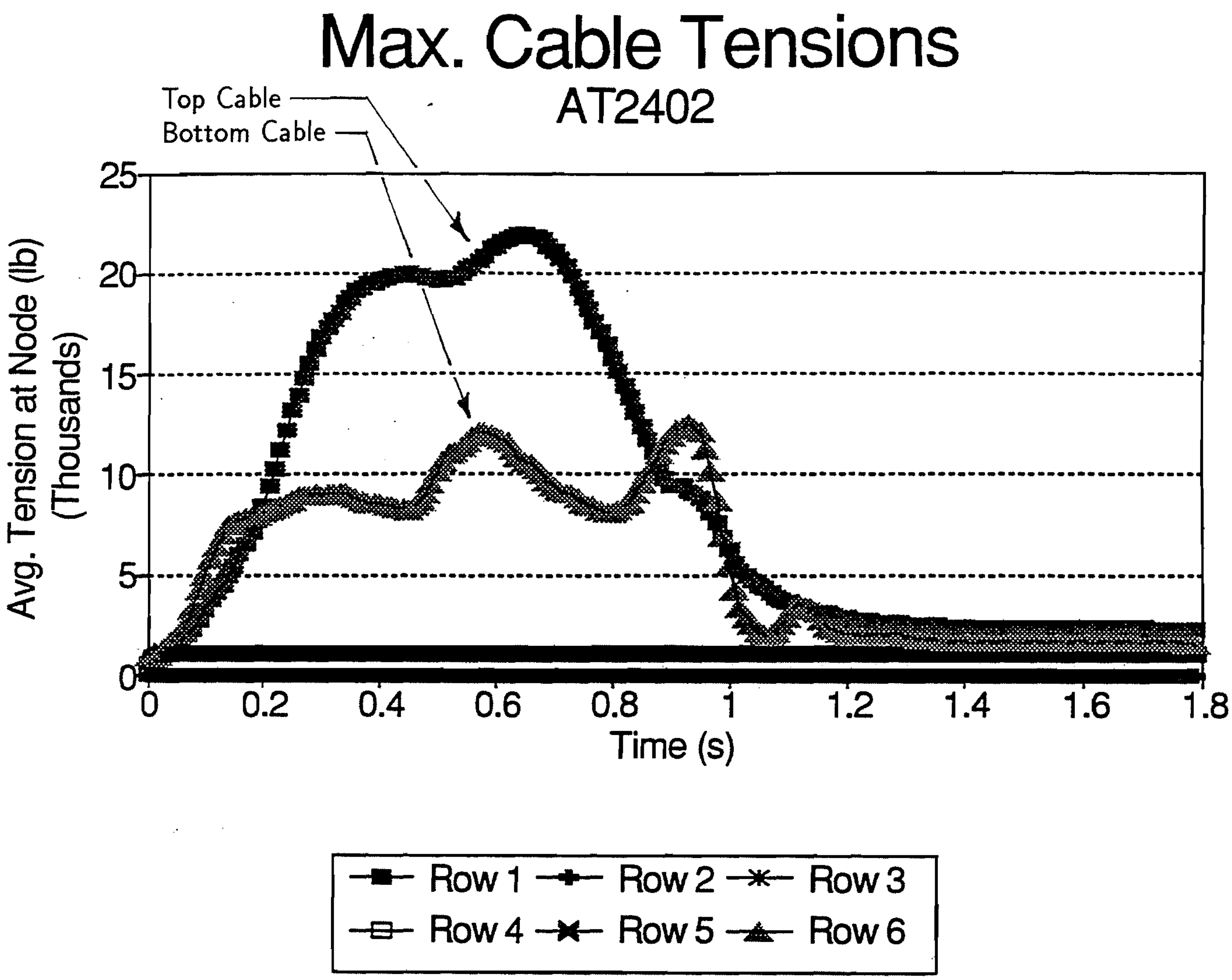
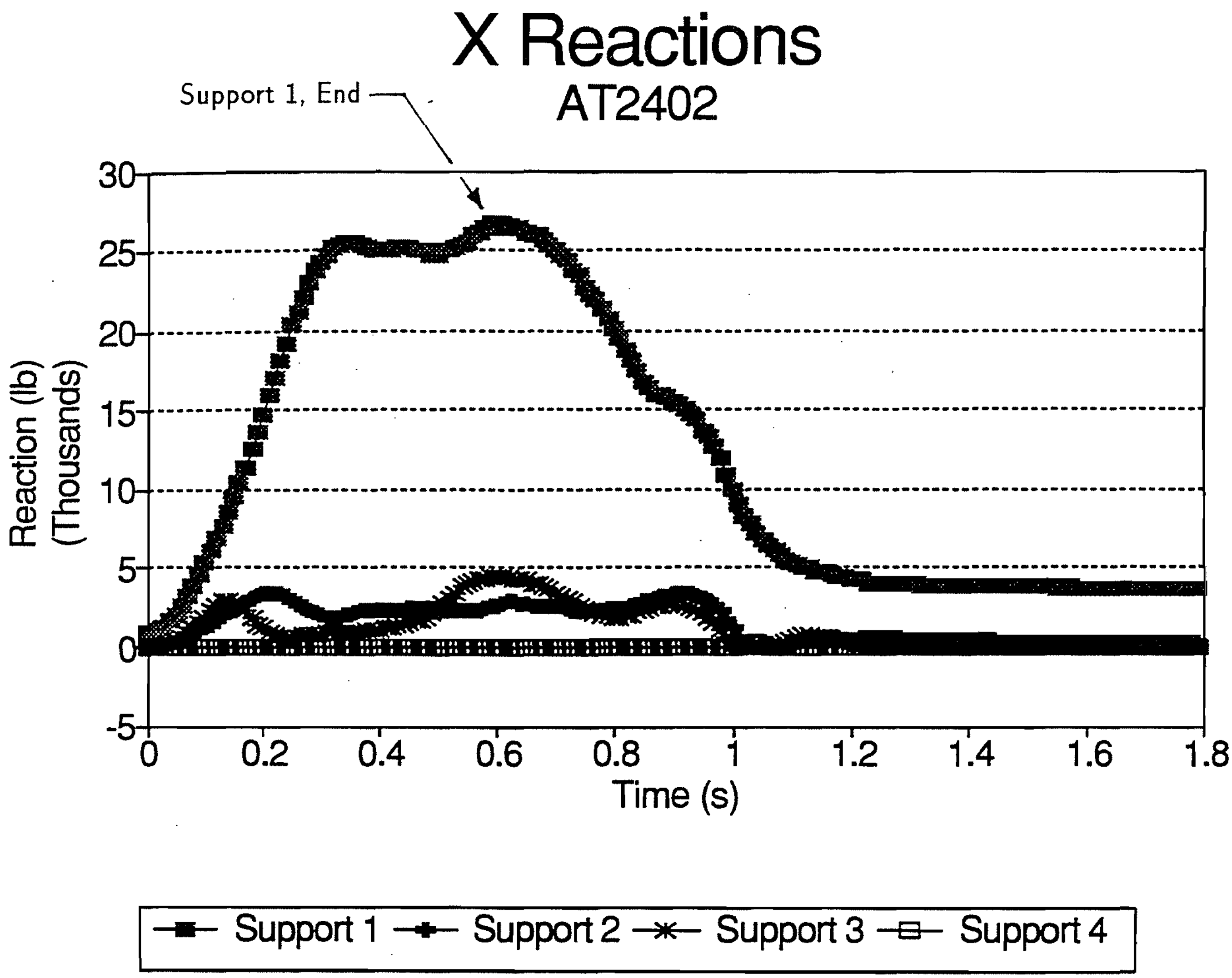
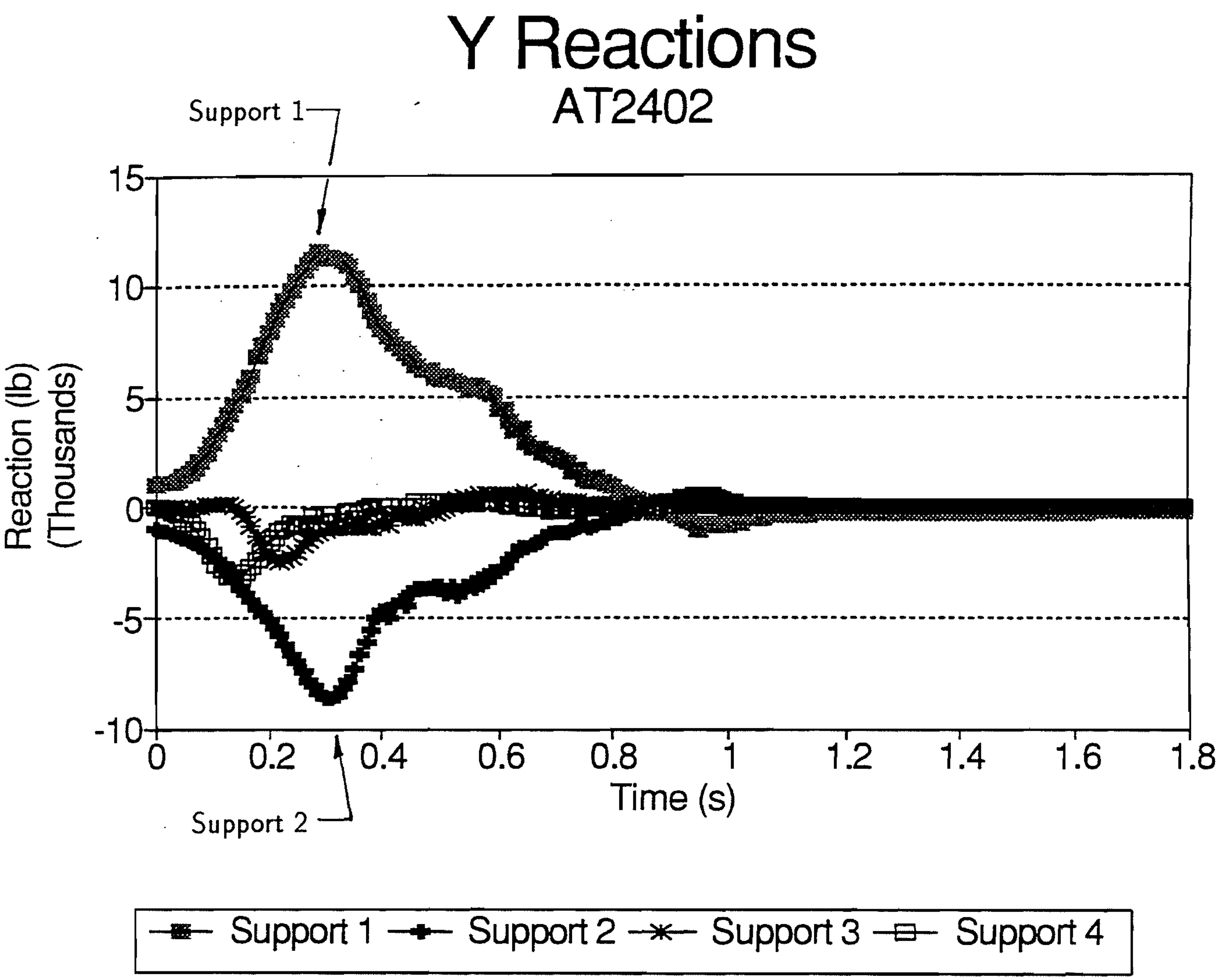


Figure III - 69
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model A.T



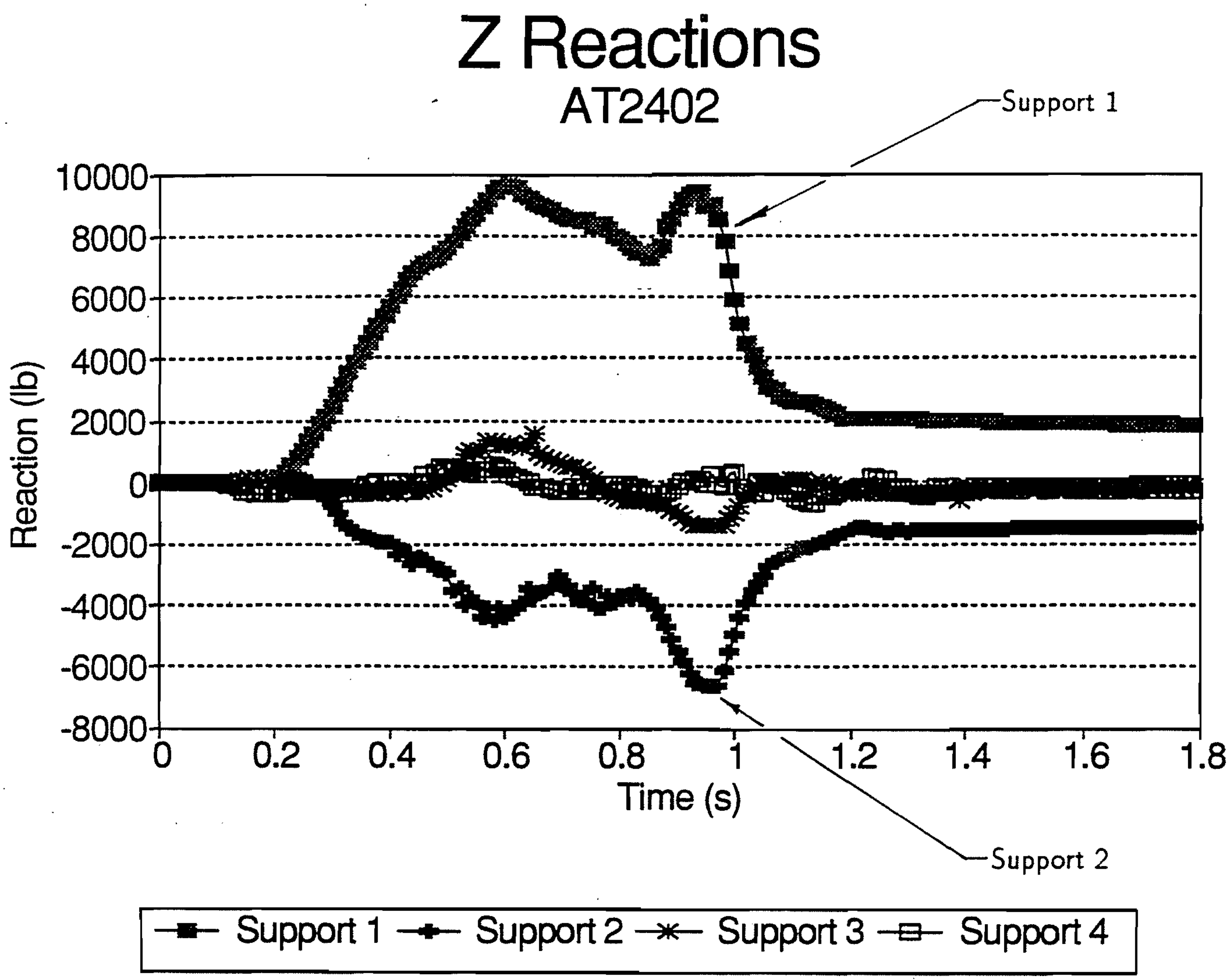
X Reaction, in-plane

Figure III - 70
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model A.T



Y Reaction, Vertical

Figure III - 71
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model A.T



Z Reaction, Downslope

Figure III - 72
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model A.T

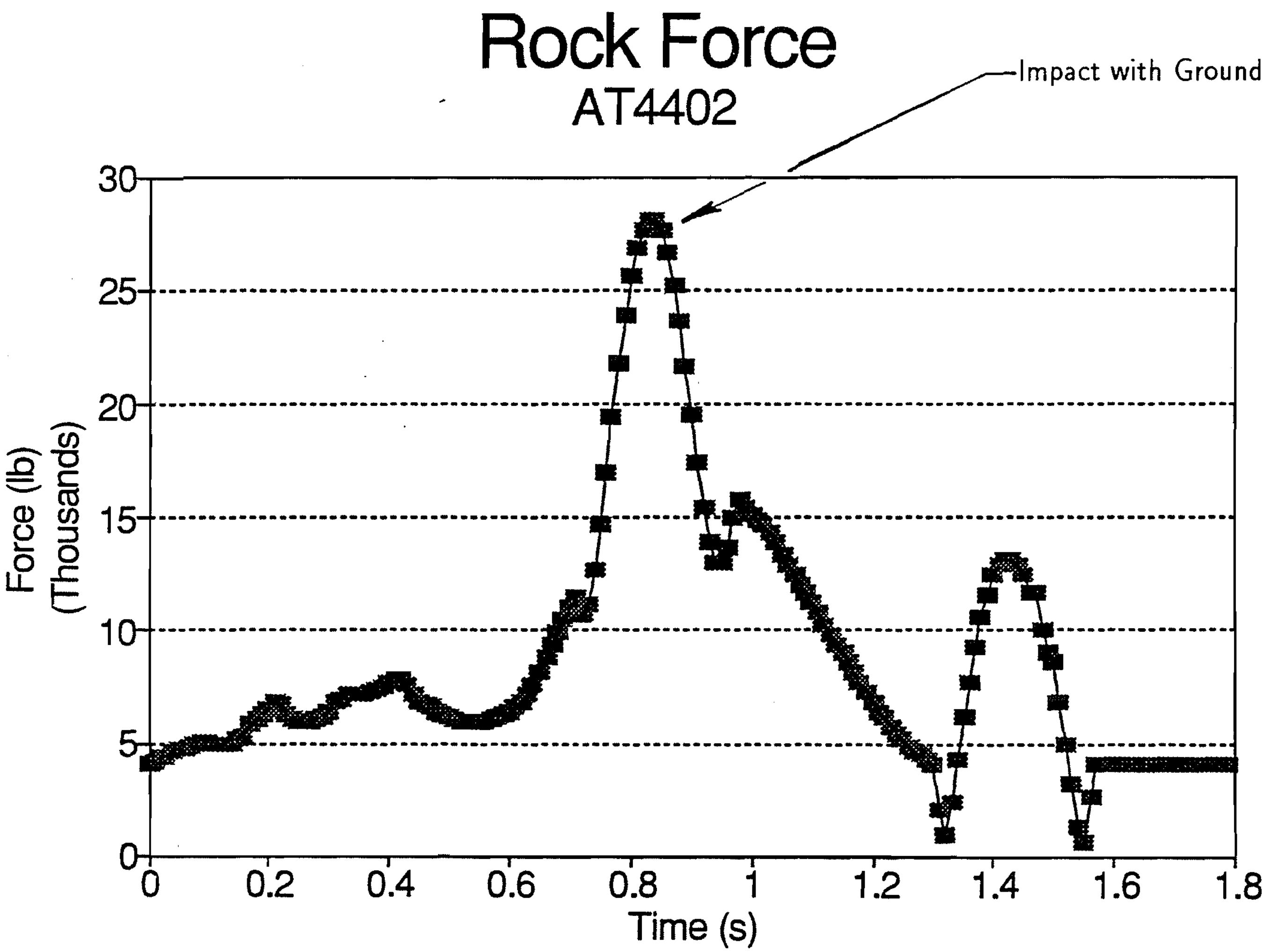


Figure III - 73
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model A.T

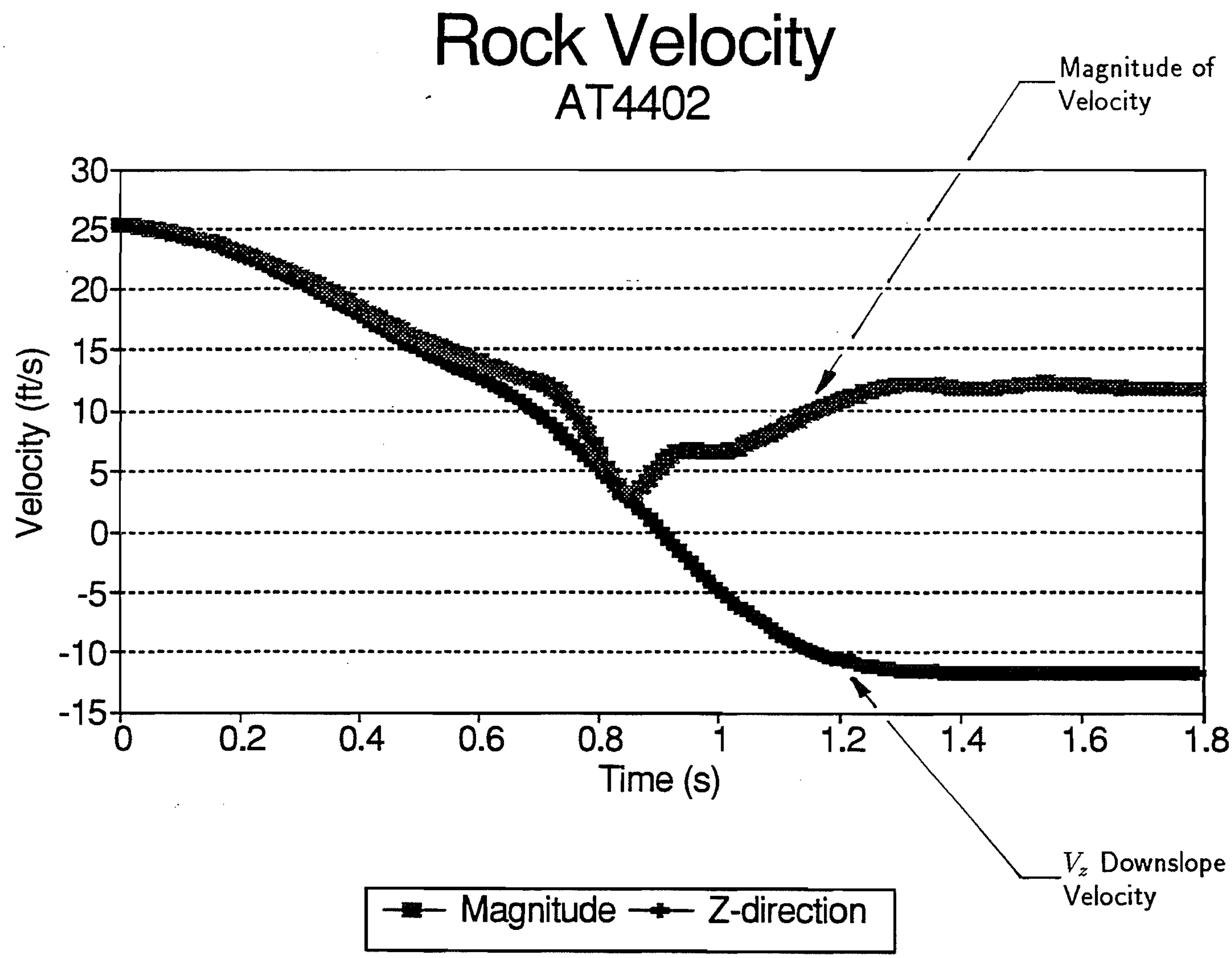


Figure III - 74
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model A.T

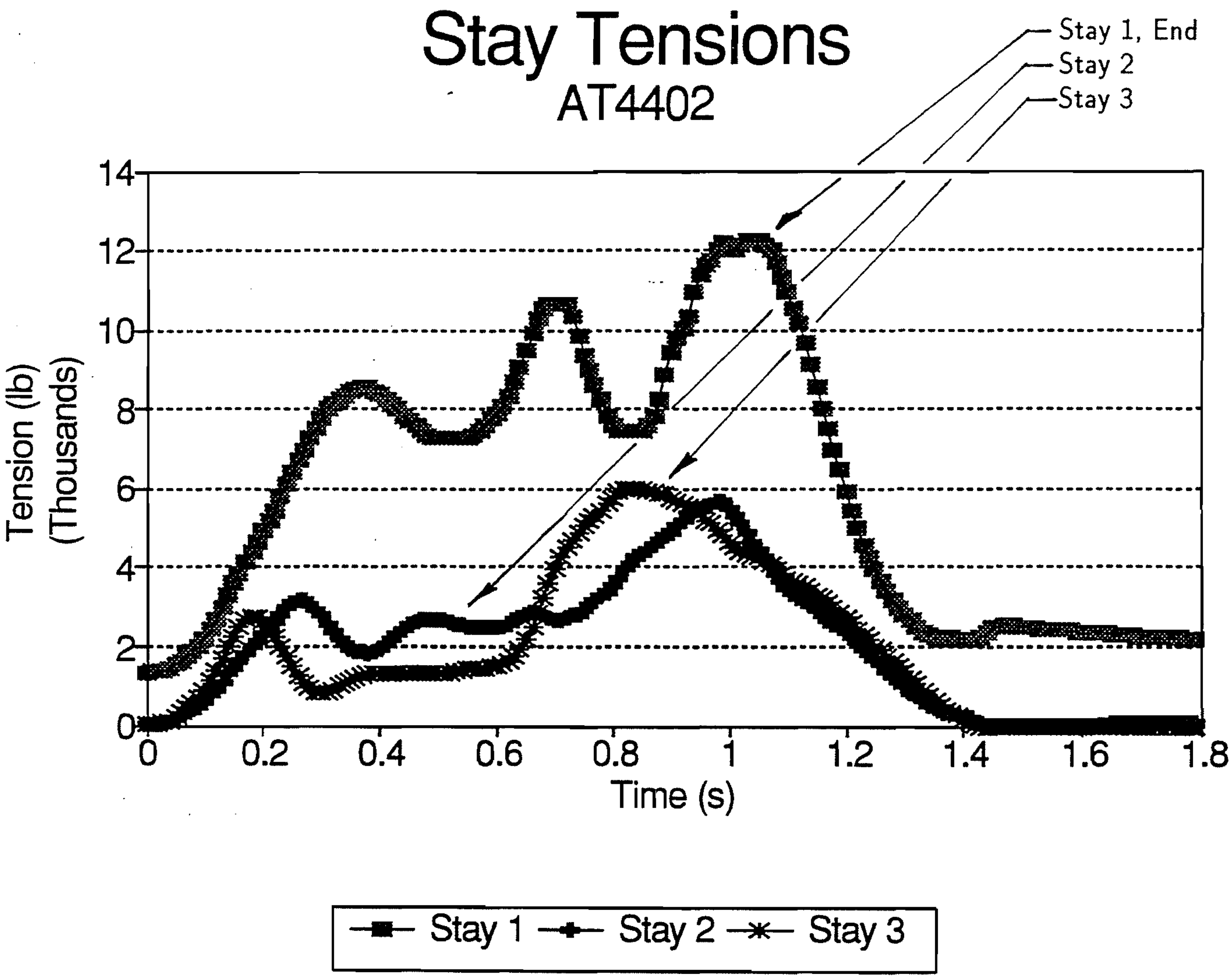


Figure III - 75
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model A.T

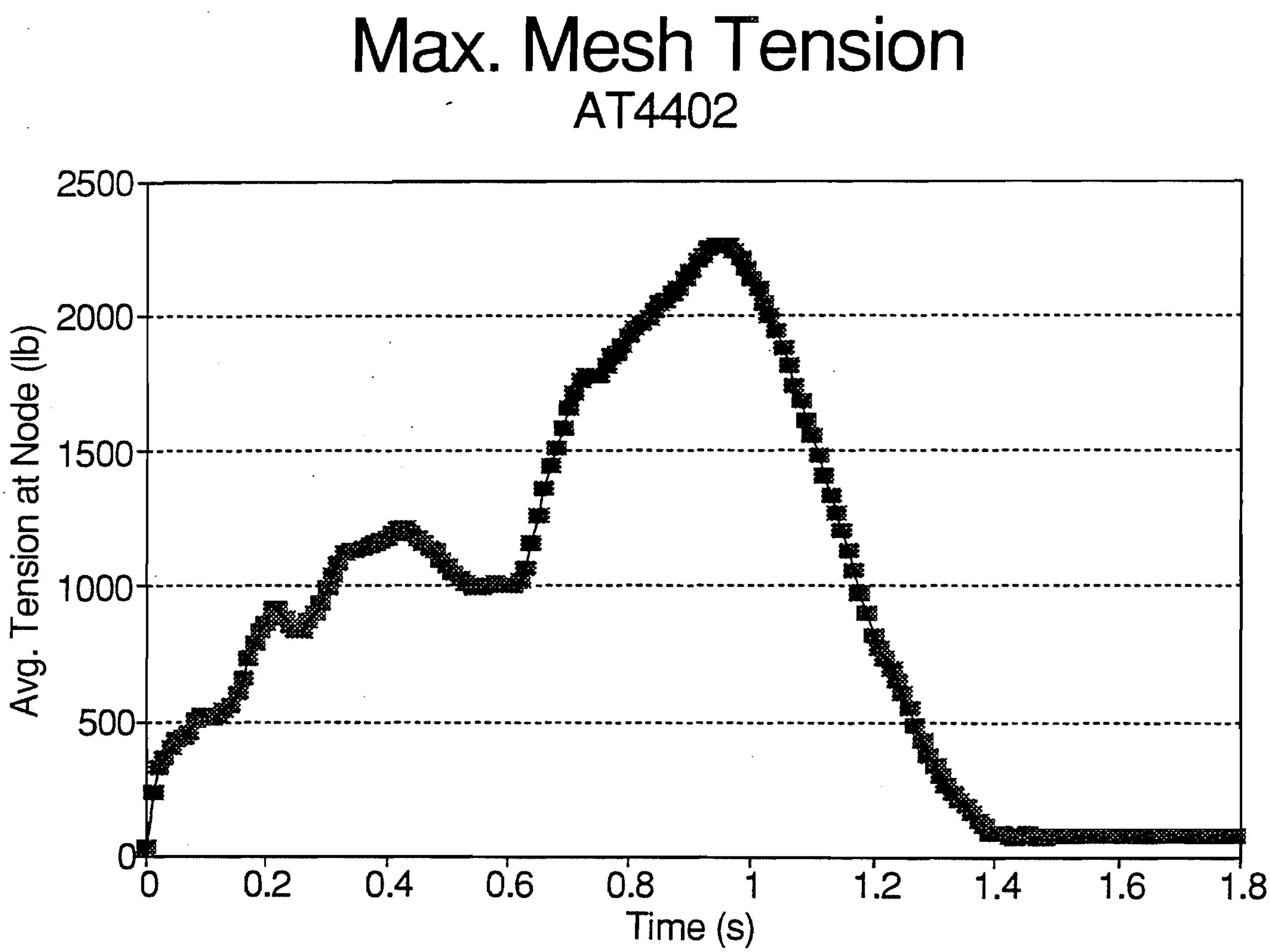


Figure III - 76
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model A.T

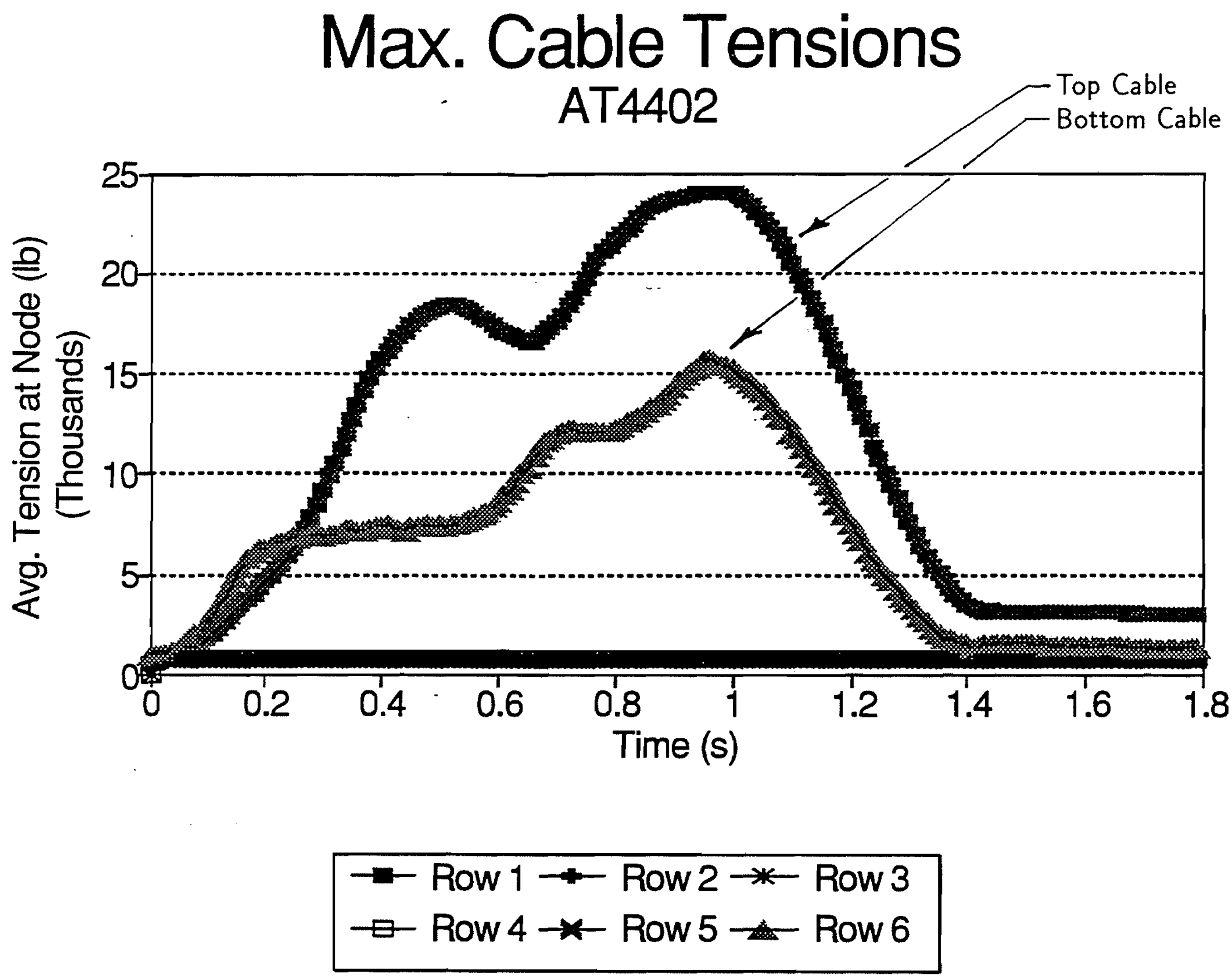
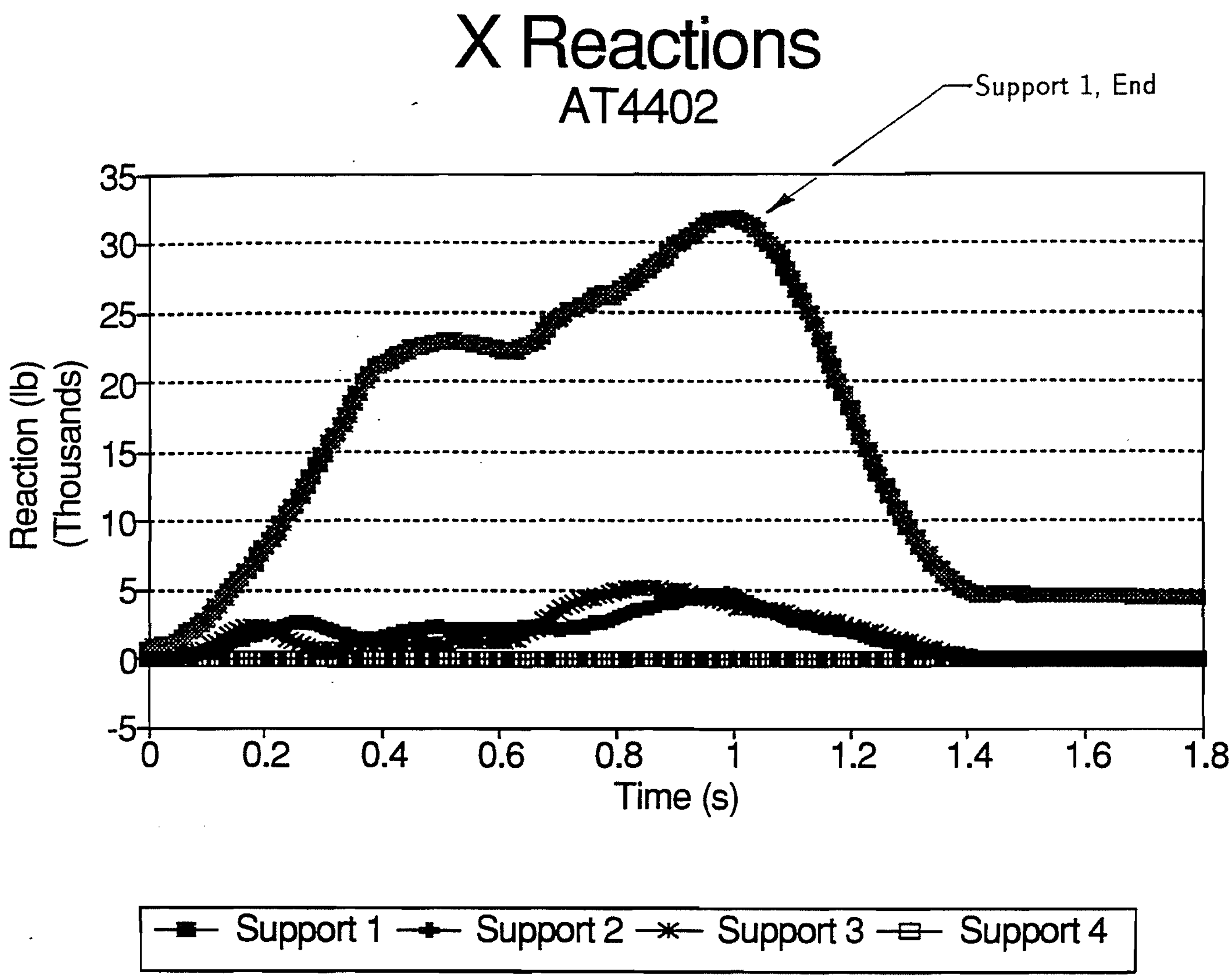
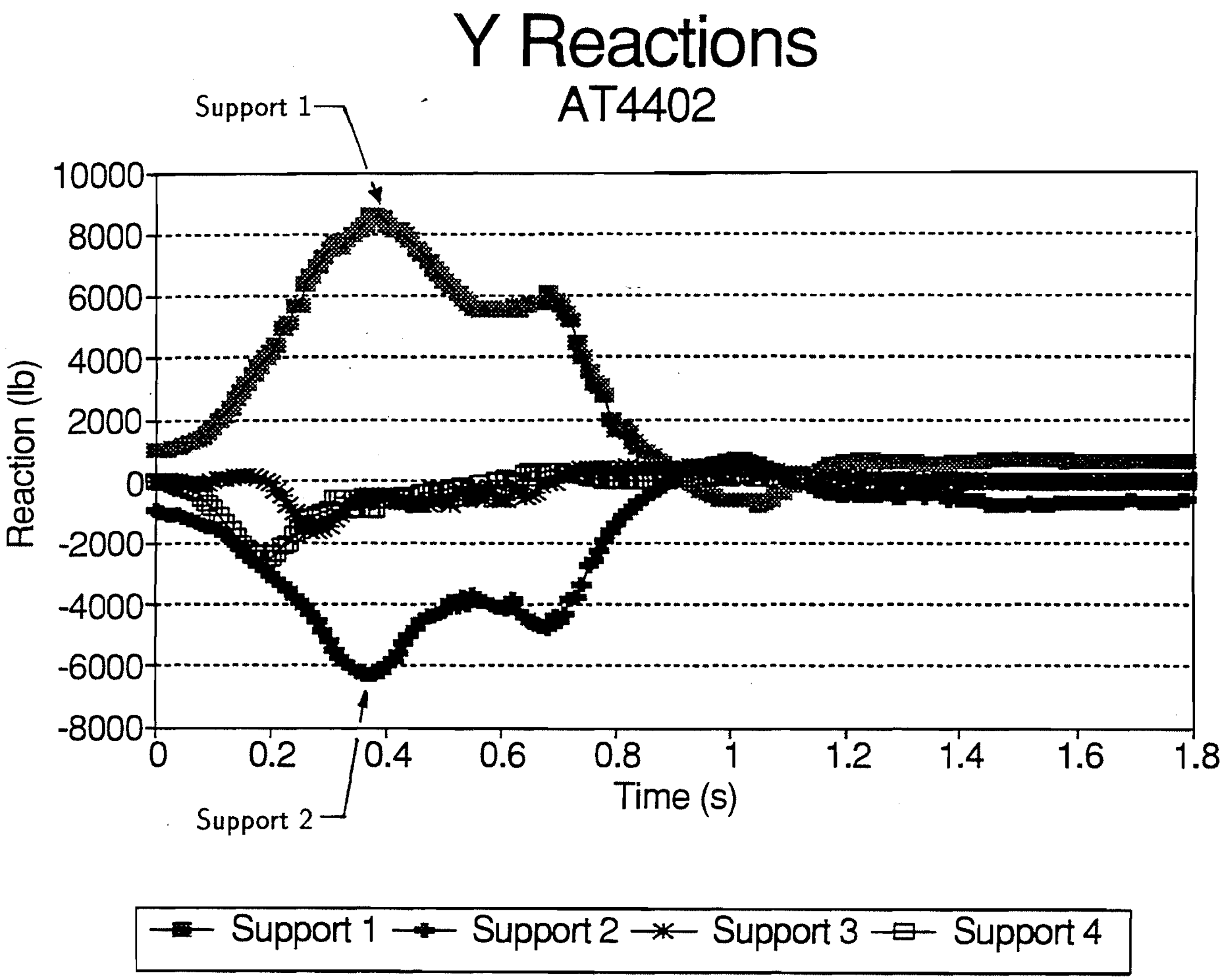


Figure III - 77
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model A.T



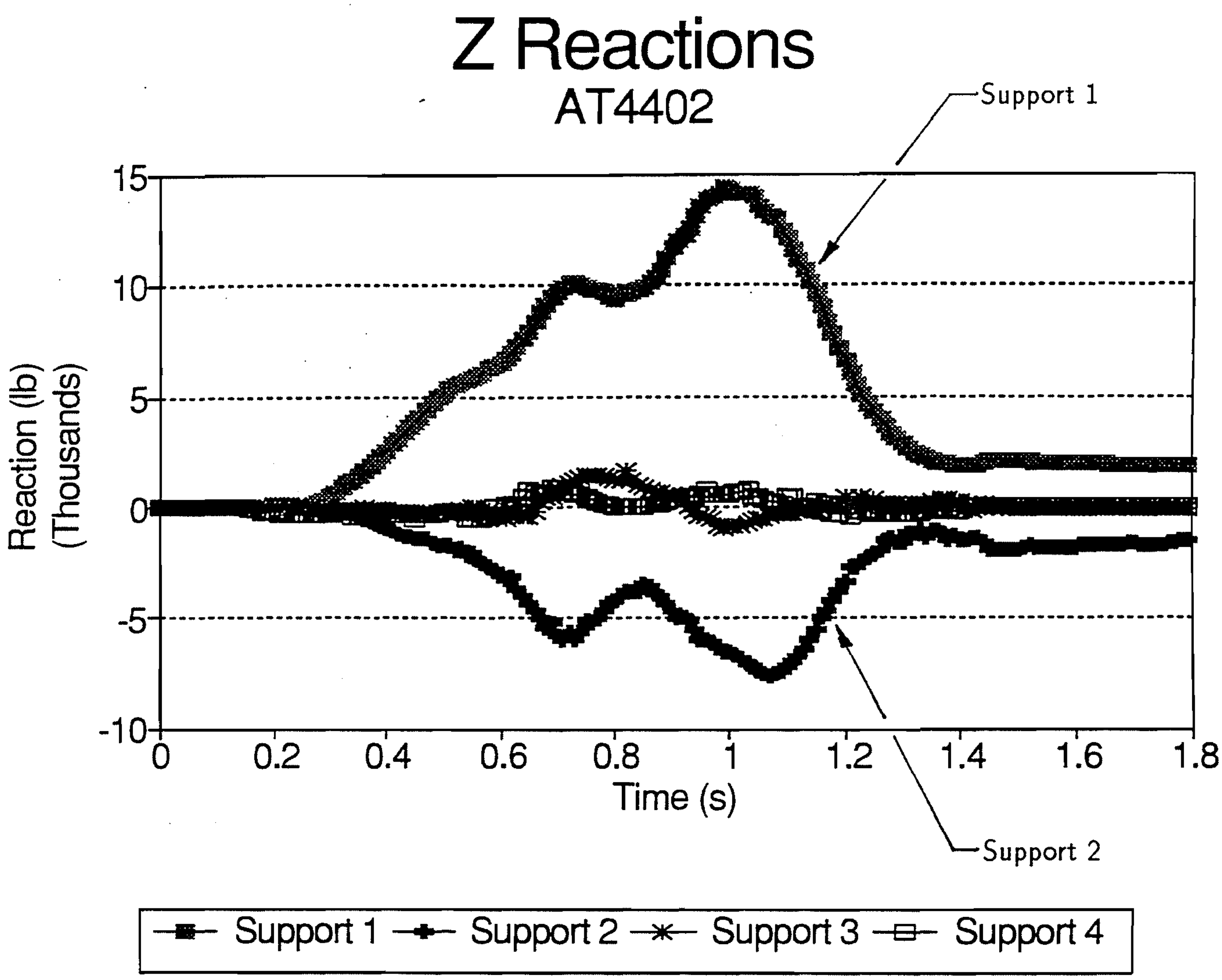
X Reaction, in-plane

Figure III - 78
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model A.T



Y Reaction, Vertical

Figure III - 79
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model A.T



Z Reaction, Downslope

Figure III - 80
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model A.T

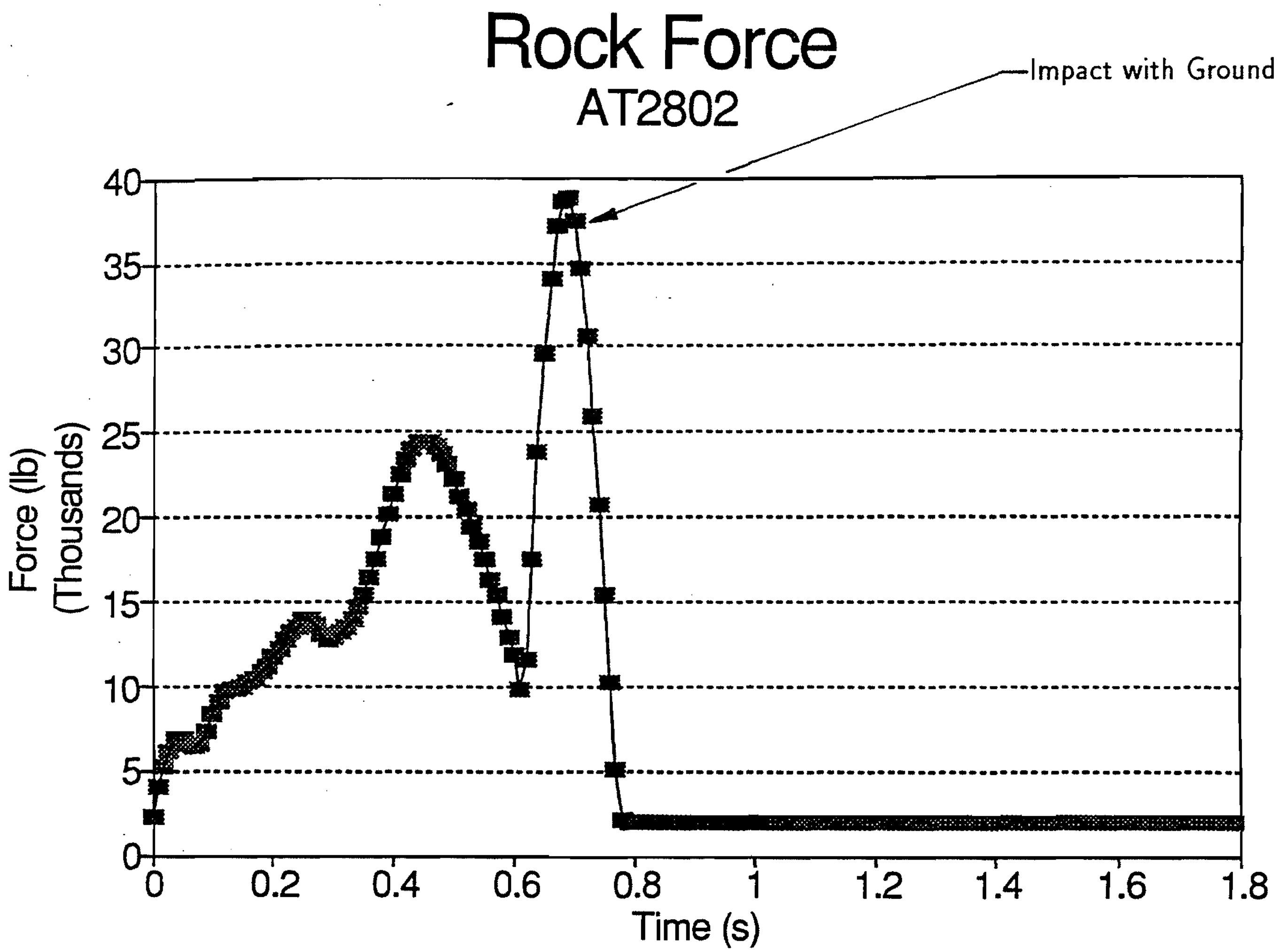


Figure III - 81
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model A.T

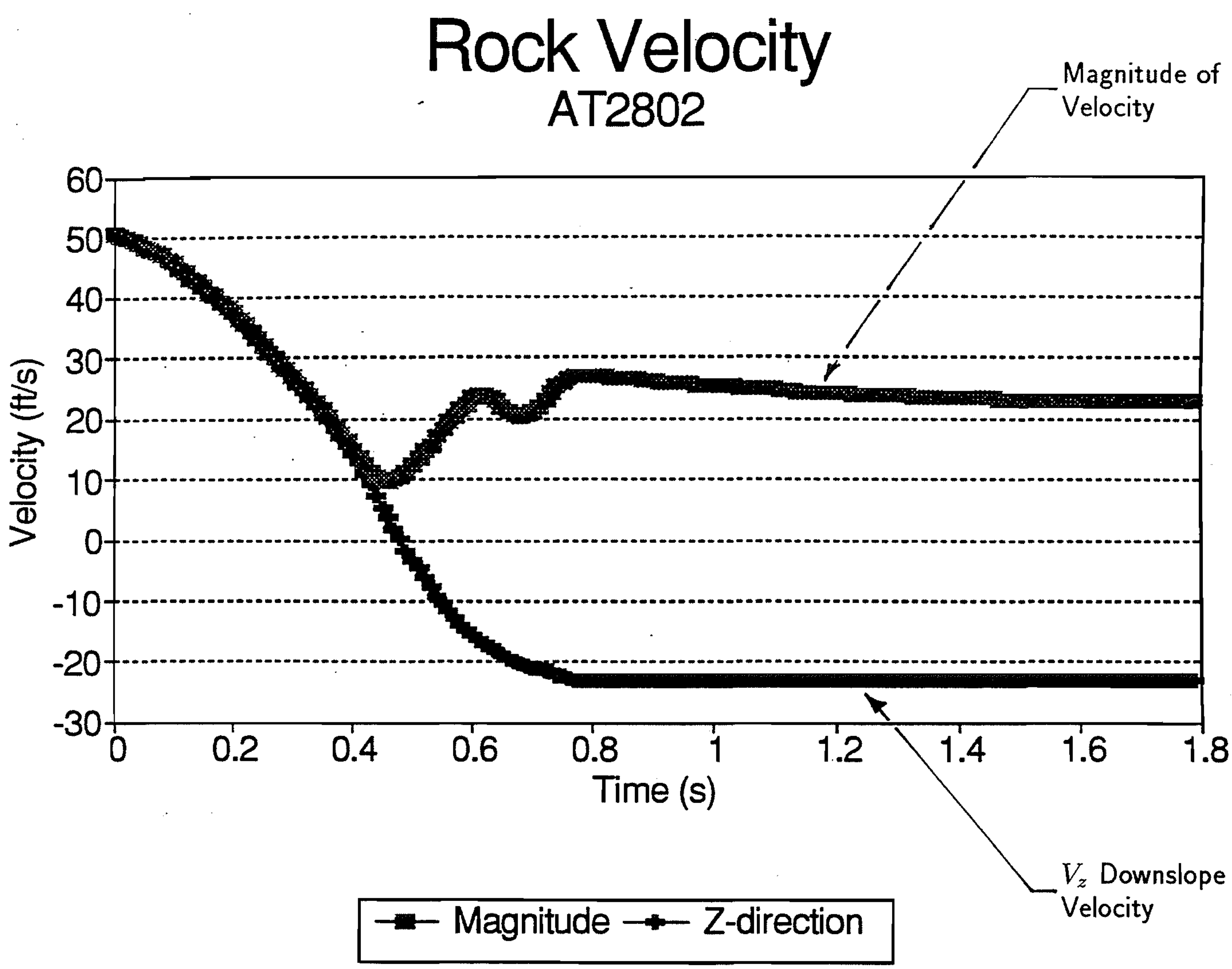


Figure III - 82
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model A.T

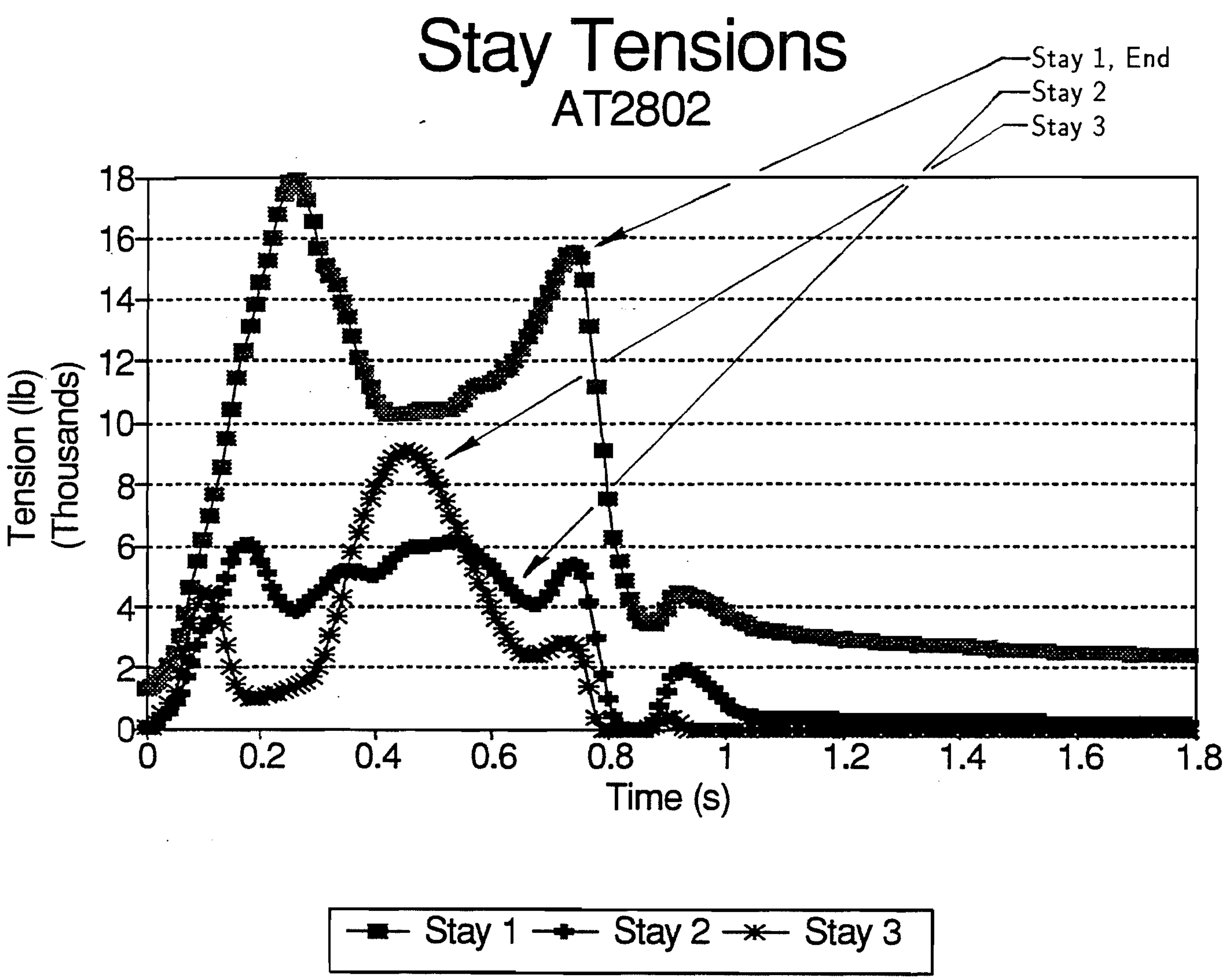


Figure III - 83
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model A.T

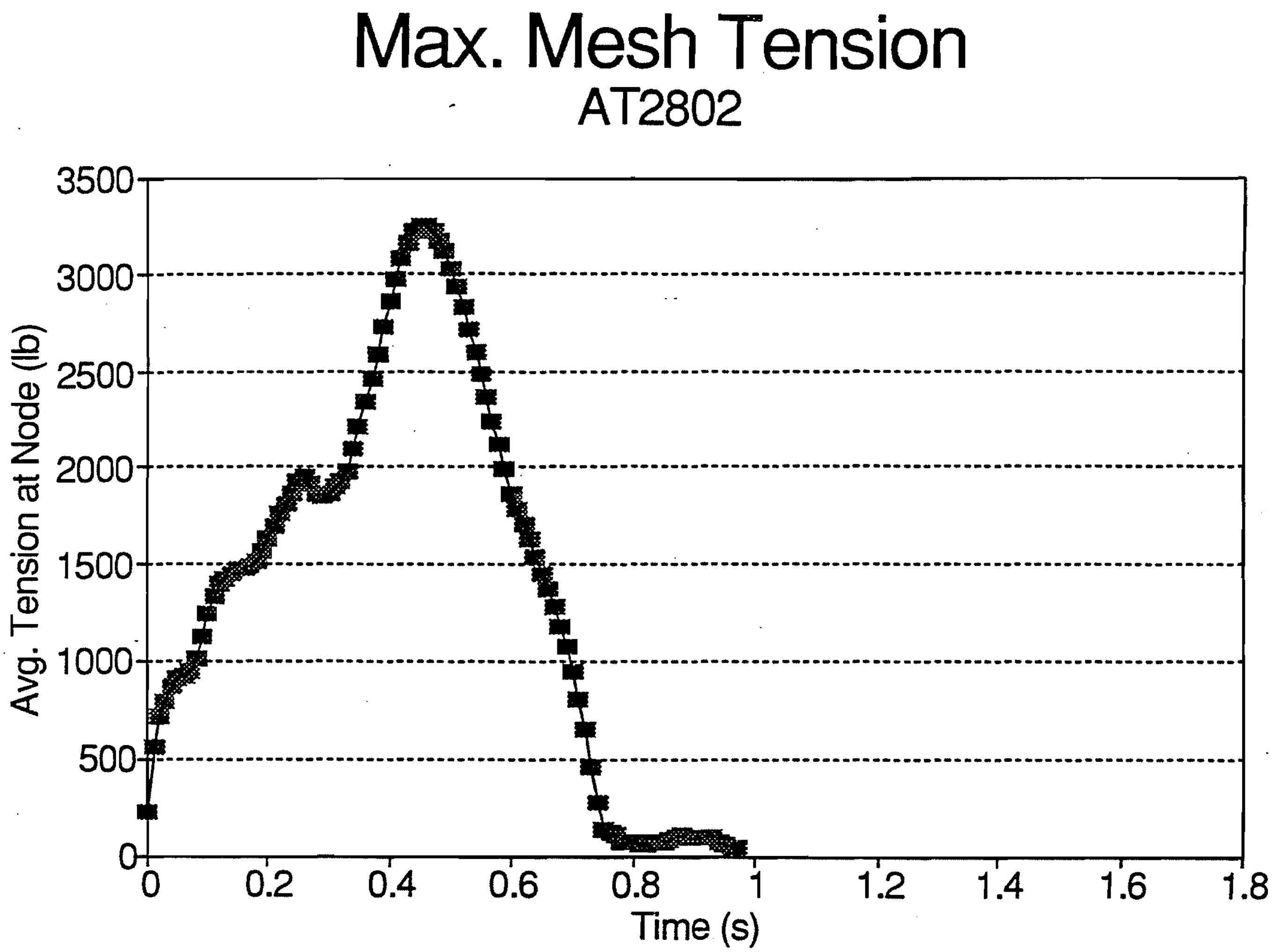


Figure III - 84
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model A.T

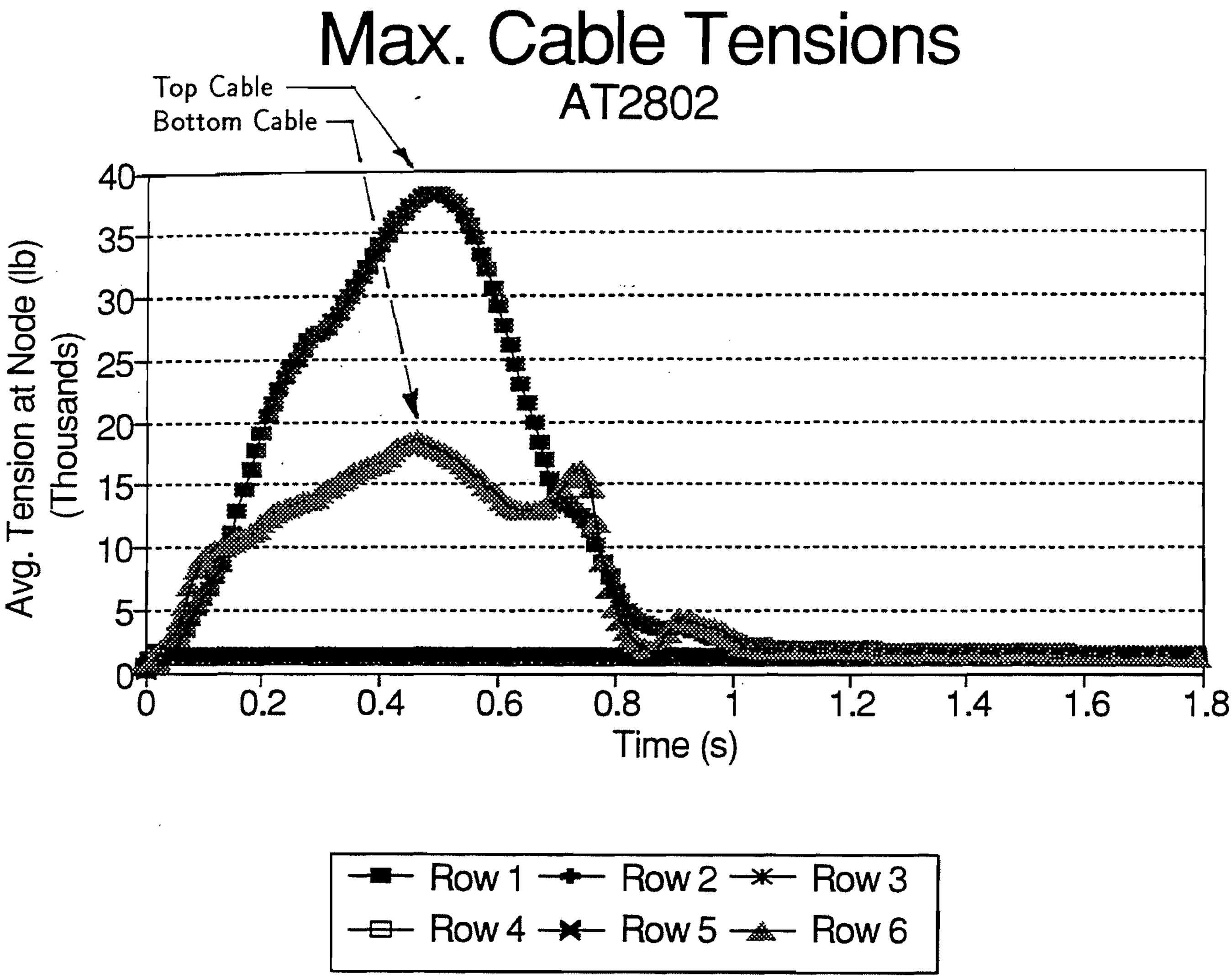
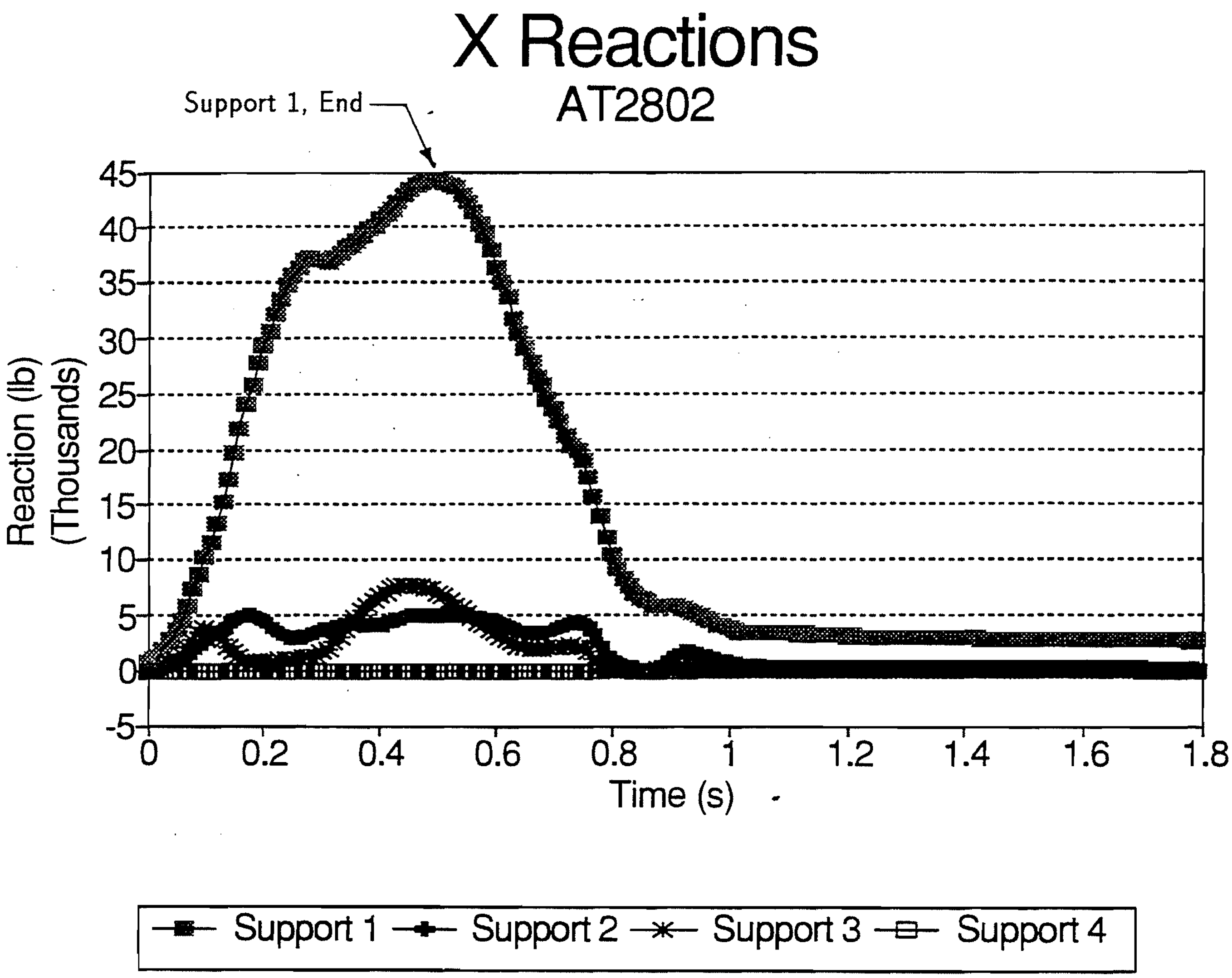
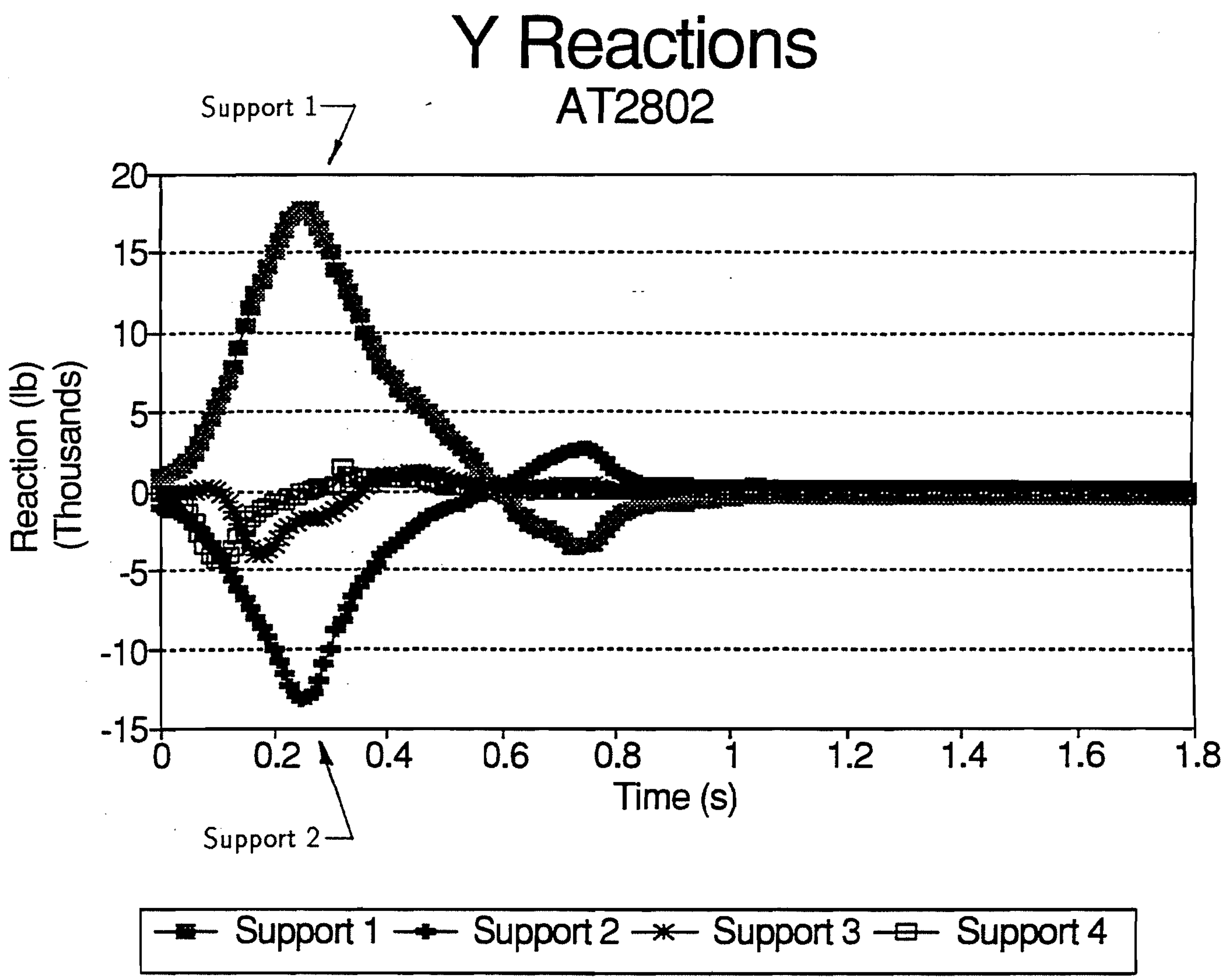


Figure III - 85
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model A.T



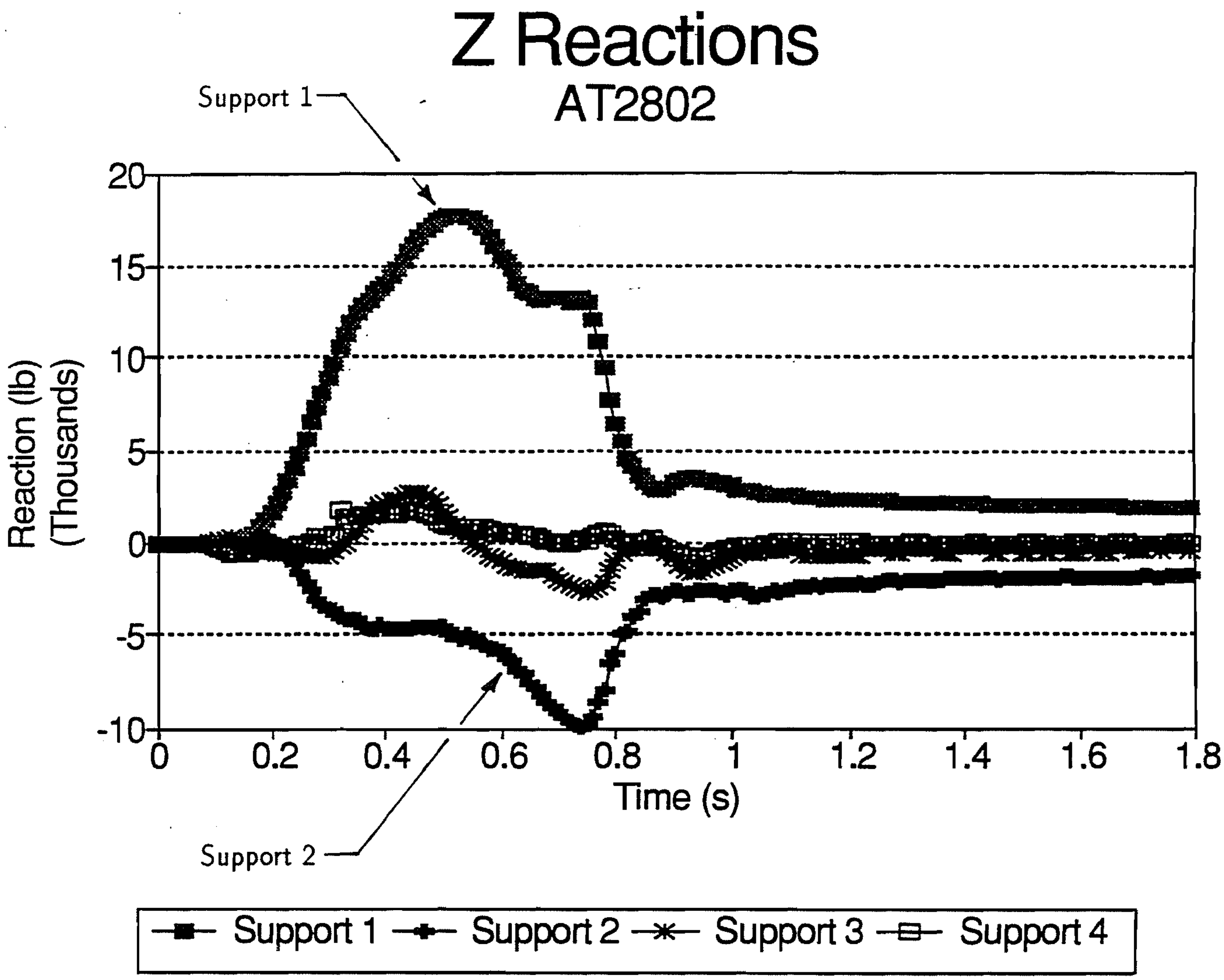
X Reaction, in-plane

Figure III - 86
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model A.T



Y Reaction, Vertical

Figure III - 87
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model A.T



Z Reaction, Downslope

Figure III - 88
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model A.T

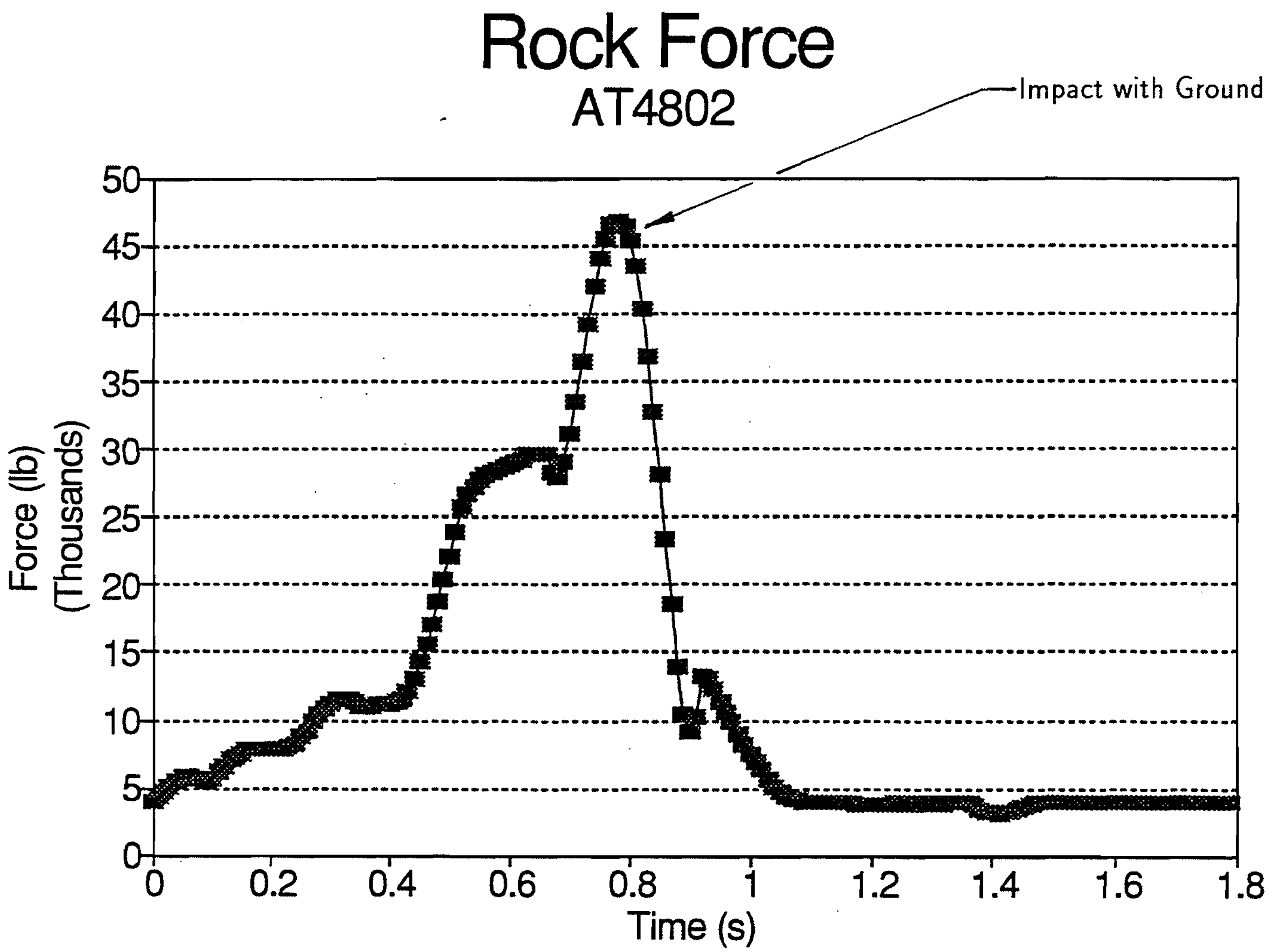


Figure III - 89
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model A.T

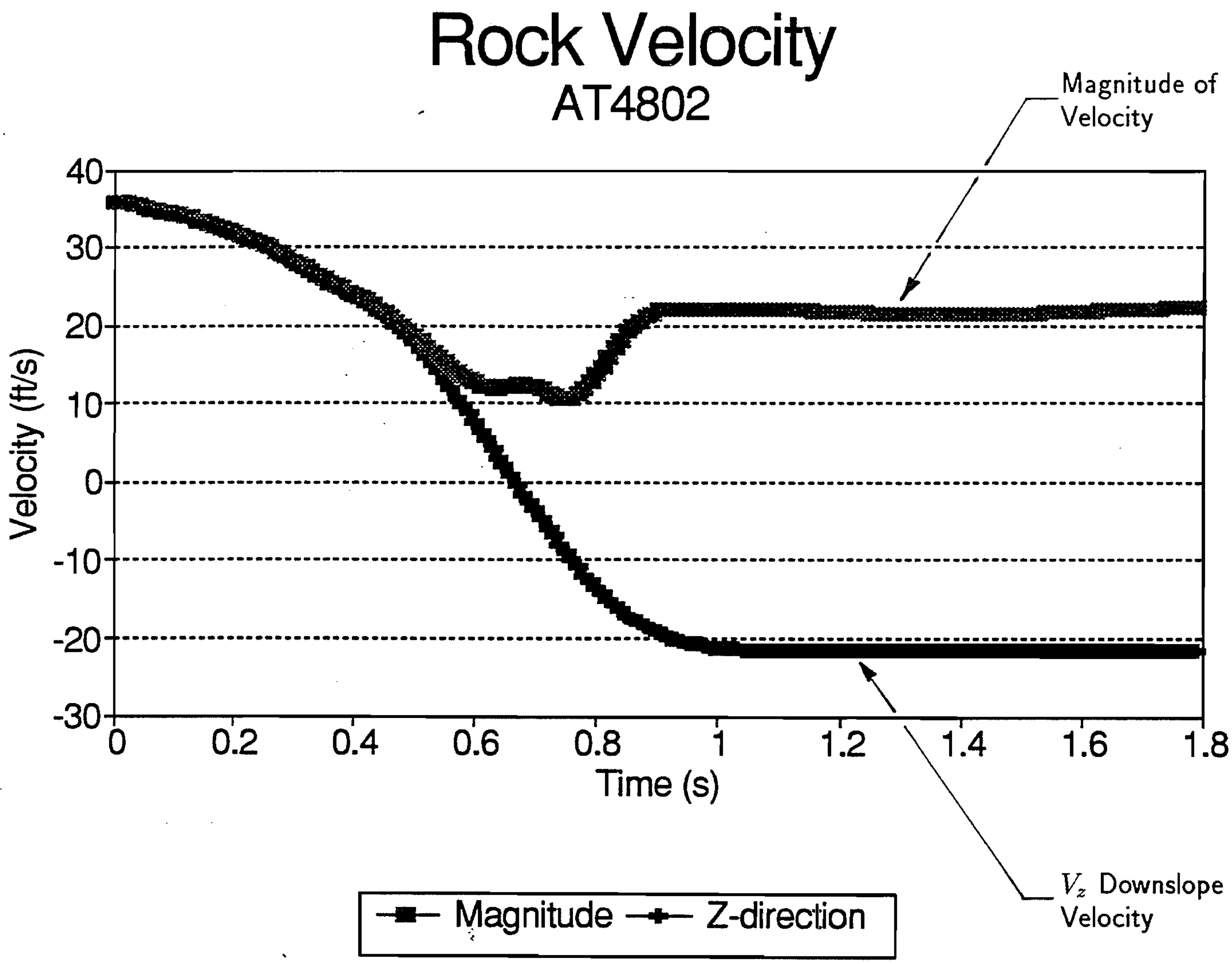


Figure III - 90
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model A.T

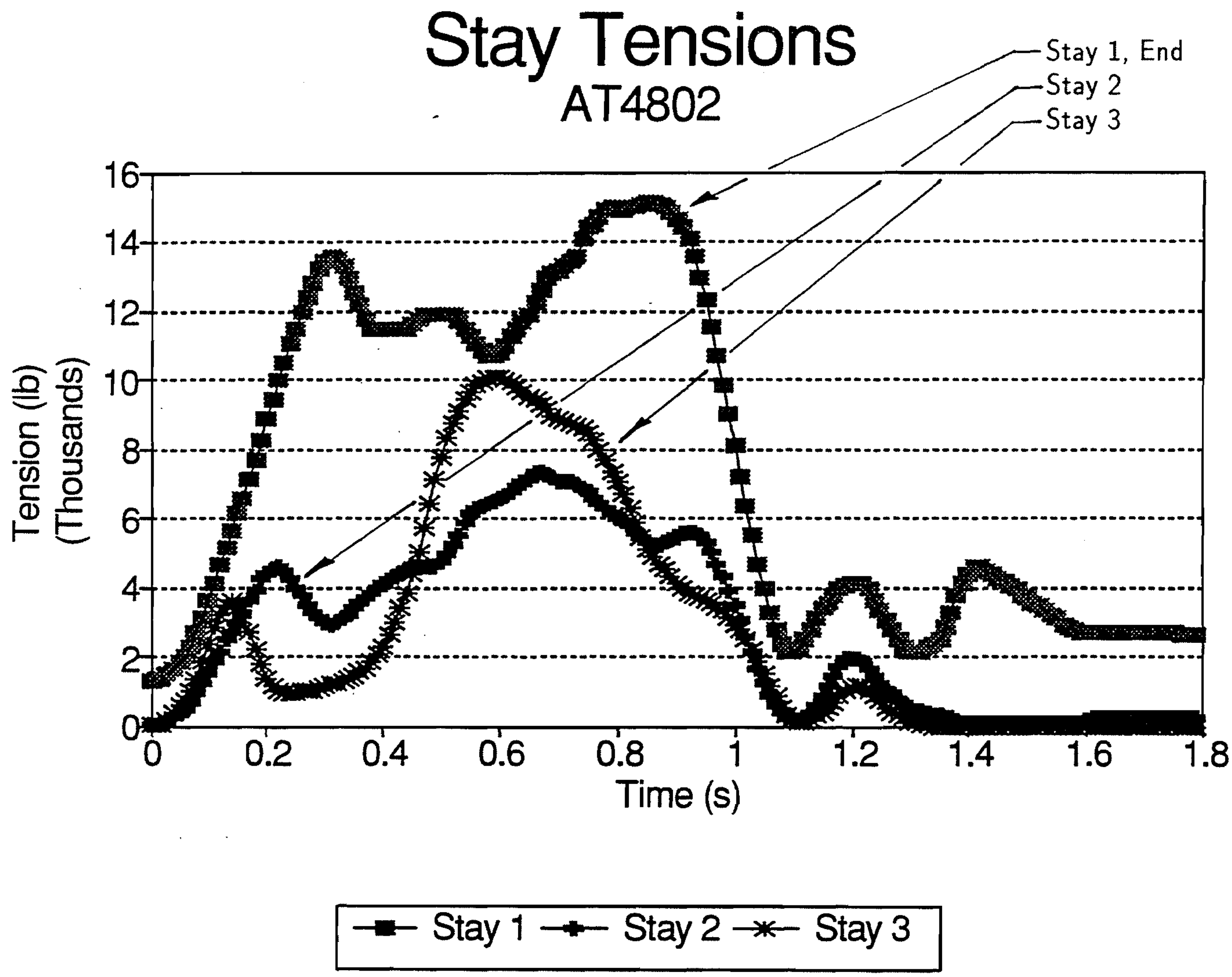


Figure III - 91
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model A.T

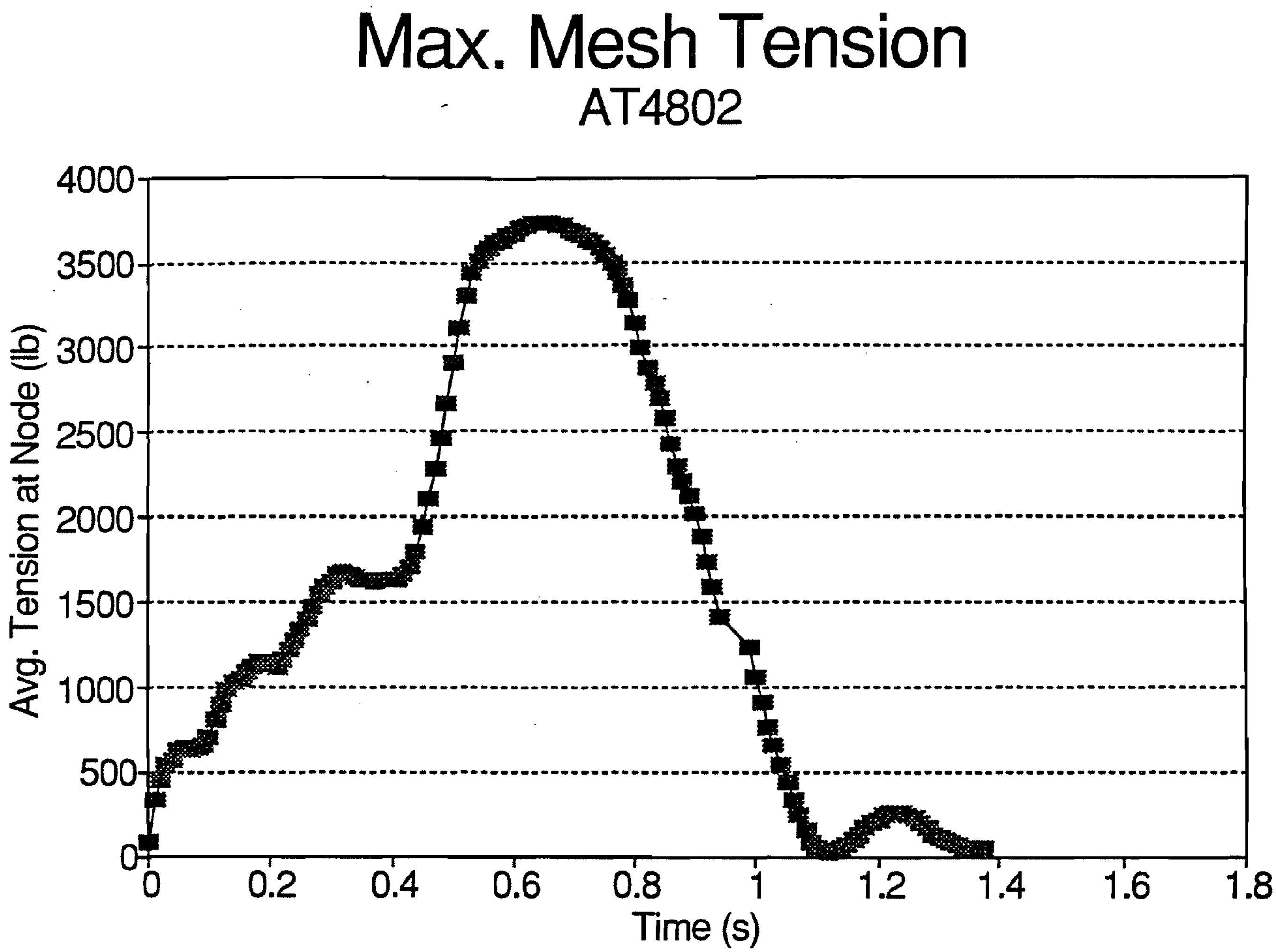


Figure III - 92
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model A.T

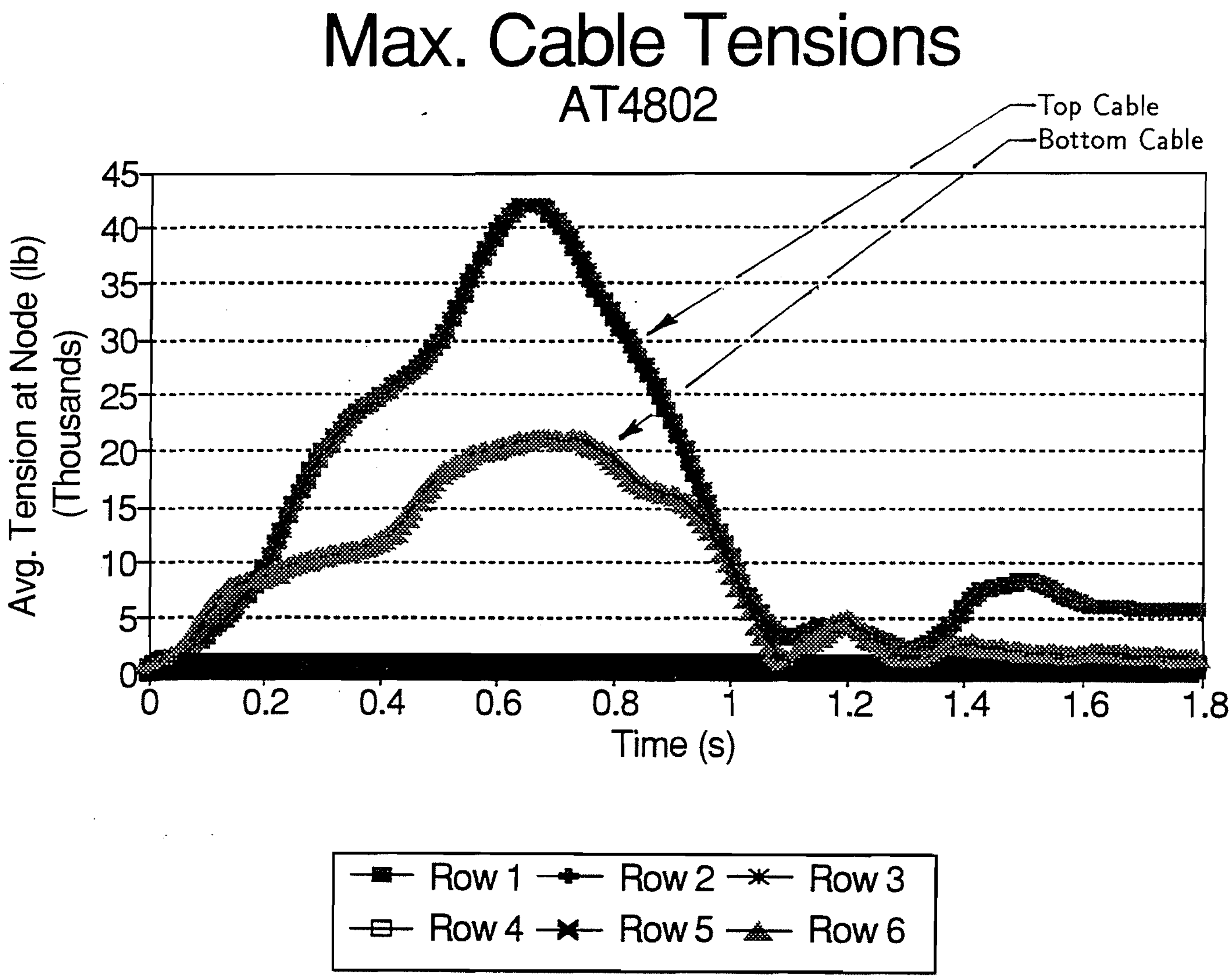
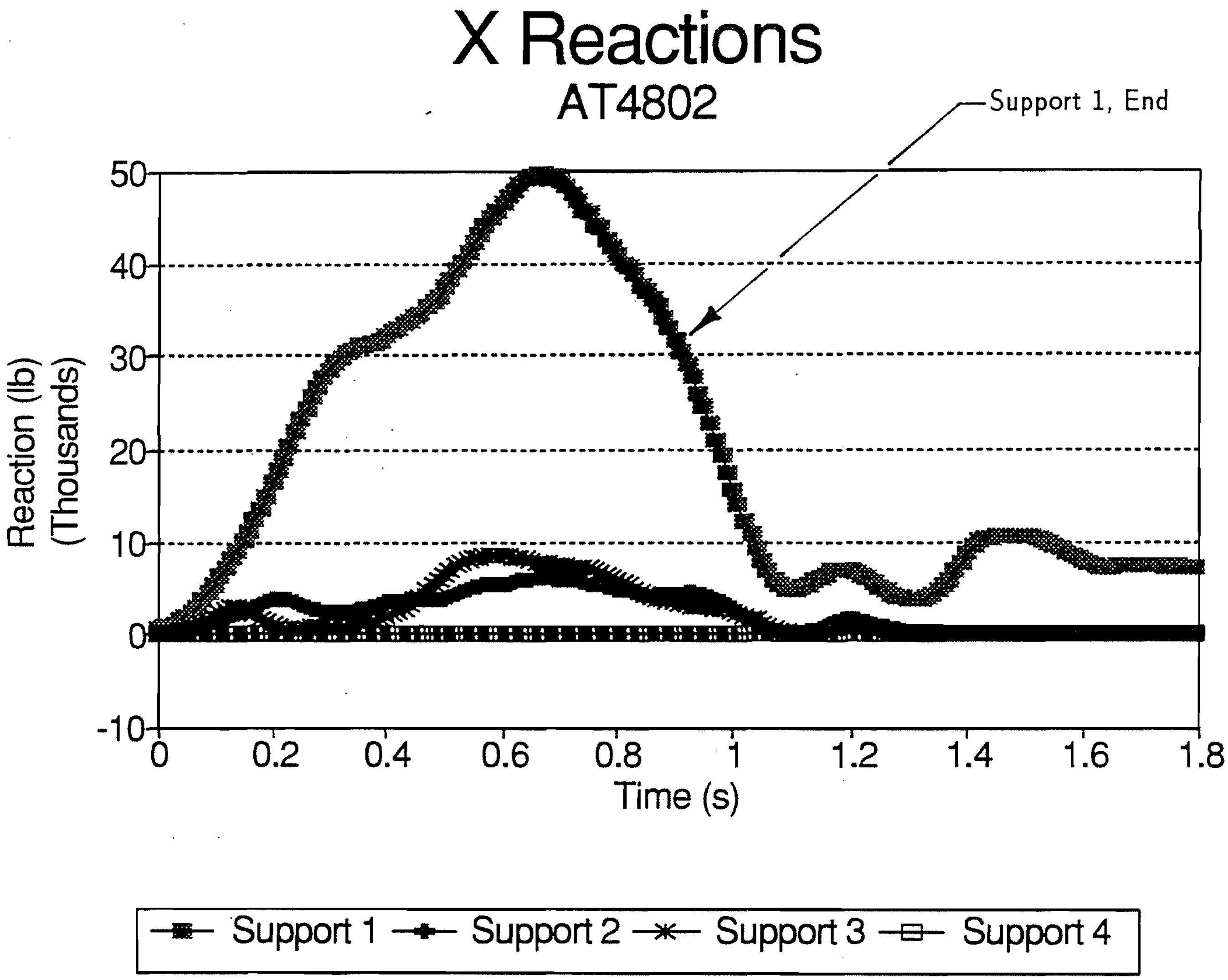
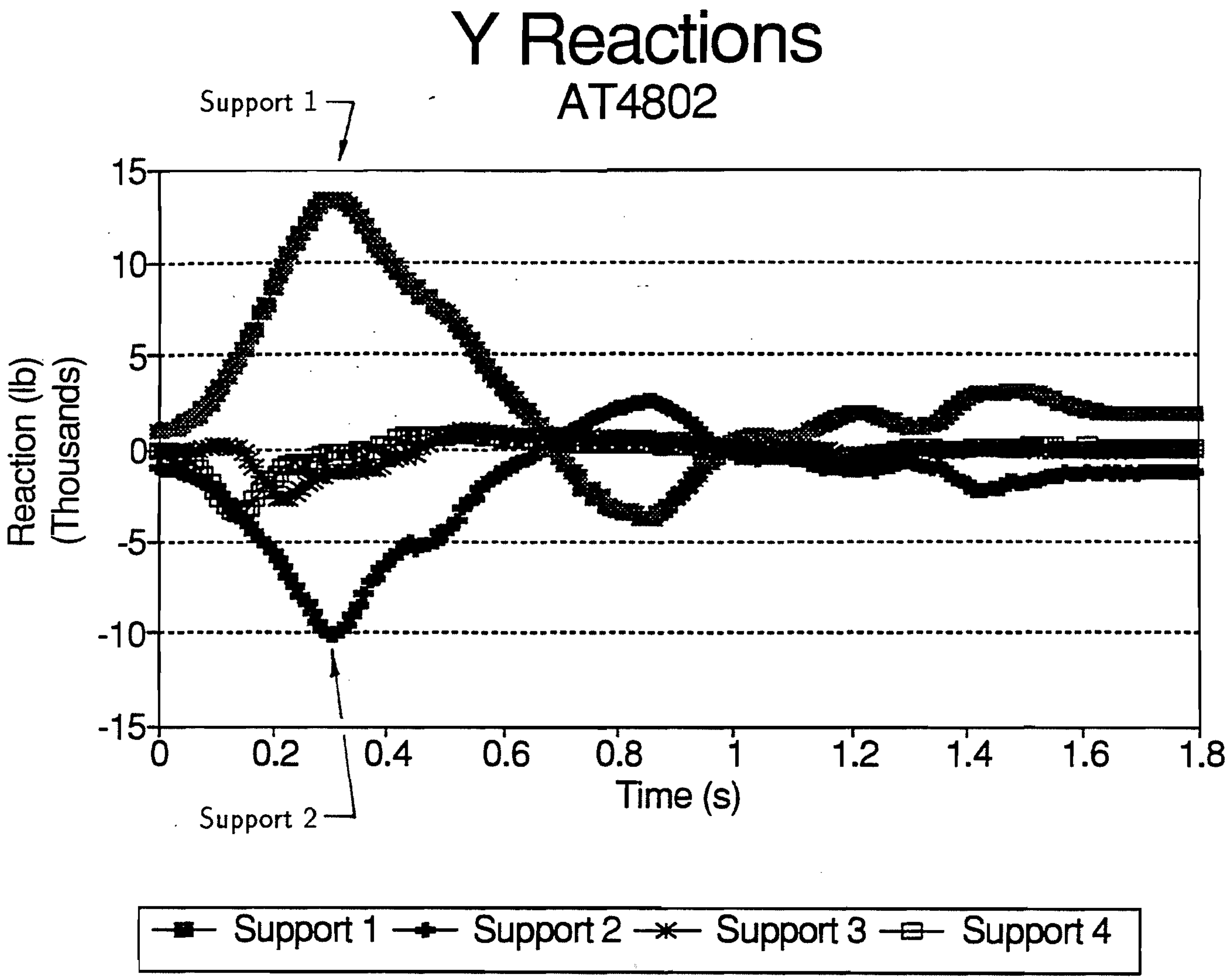


Figure III - 93
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model A.T



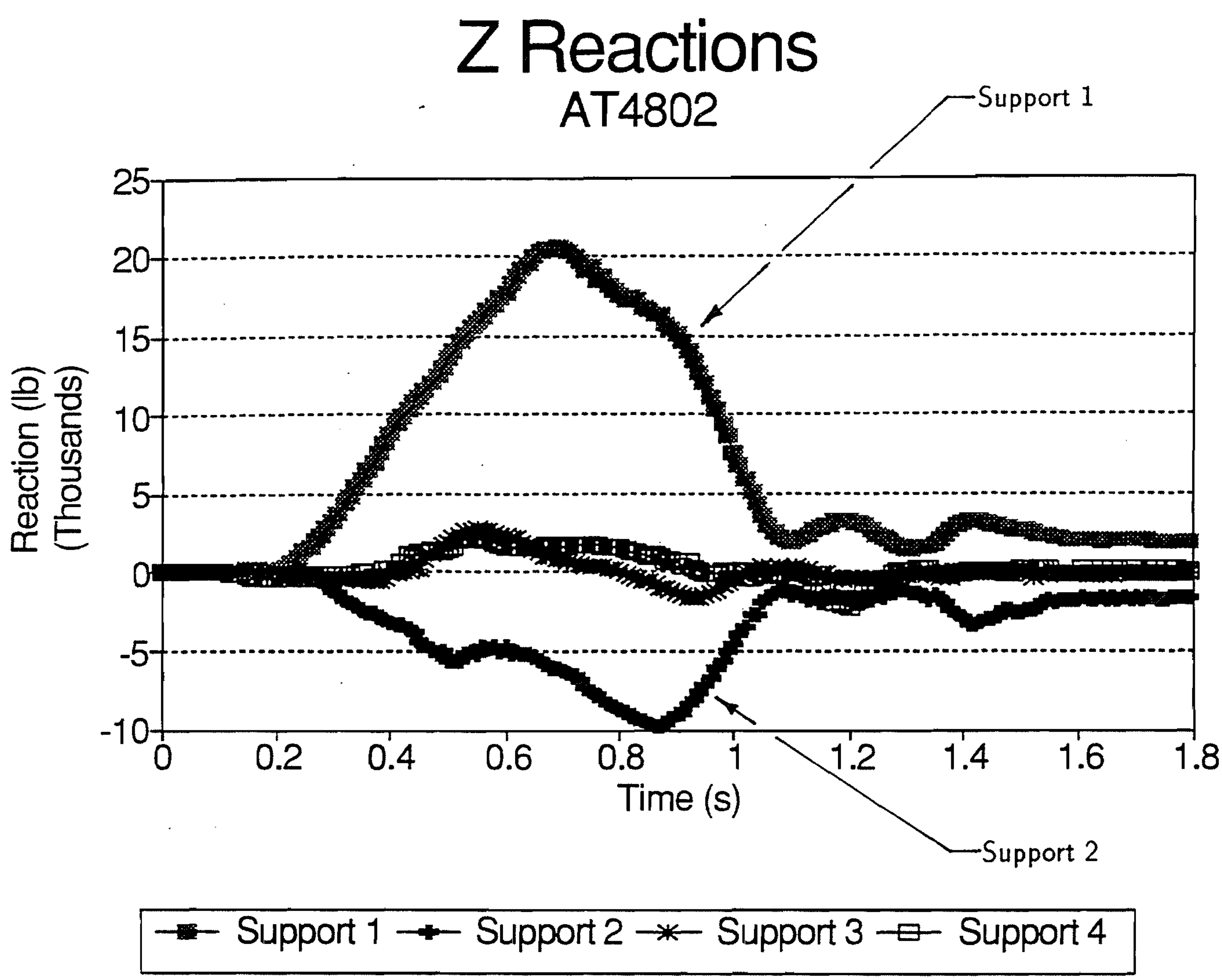
X Reaction, in-plane

Figure III - 94
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model A.T



Y Reaction, Vertical

Figure III - 95
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model A.T



Z Reaction, Downslope

Figure III - 96
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model A.T

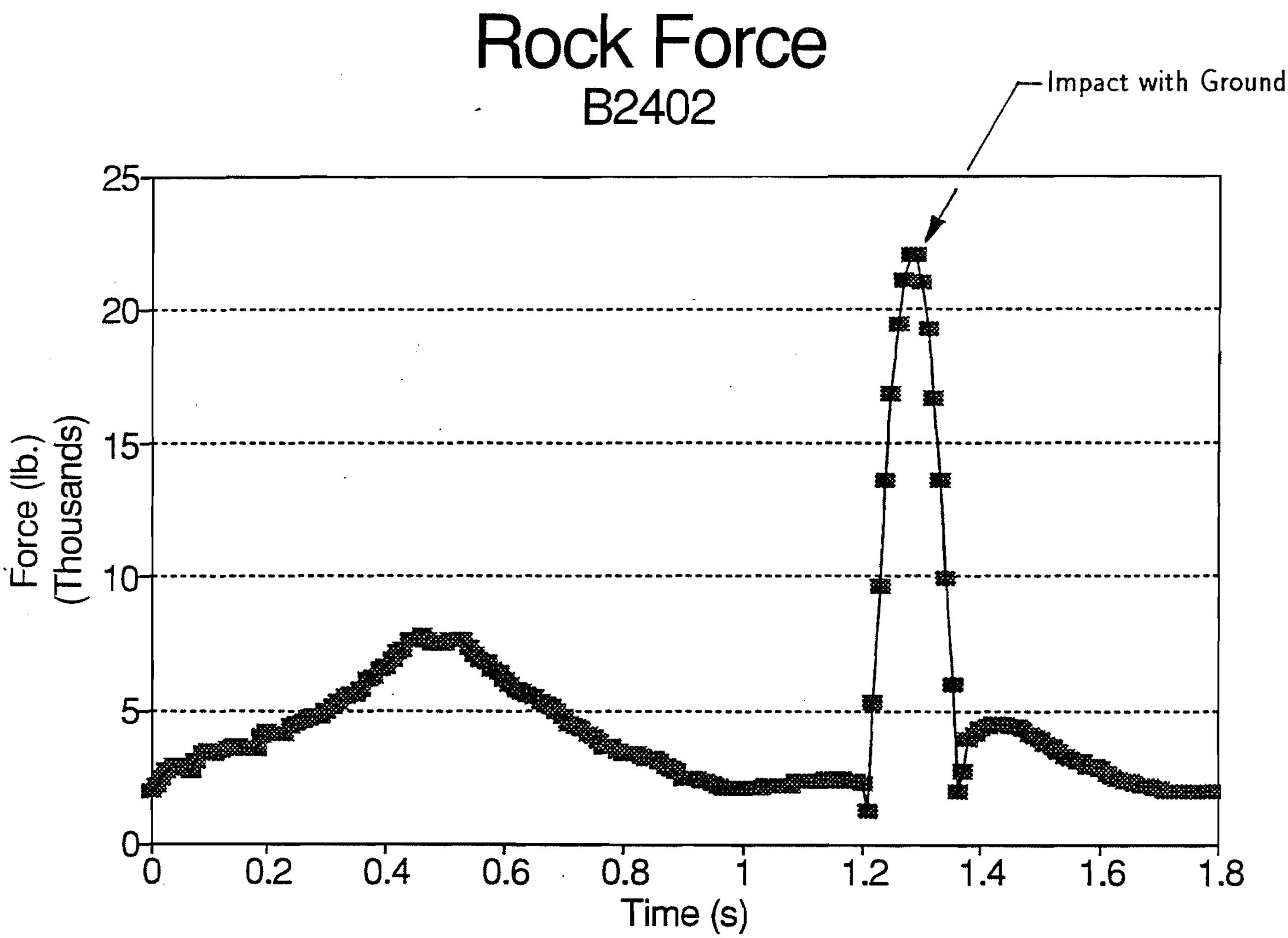


Figure III - 97
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model B

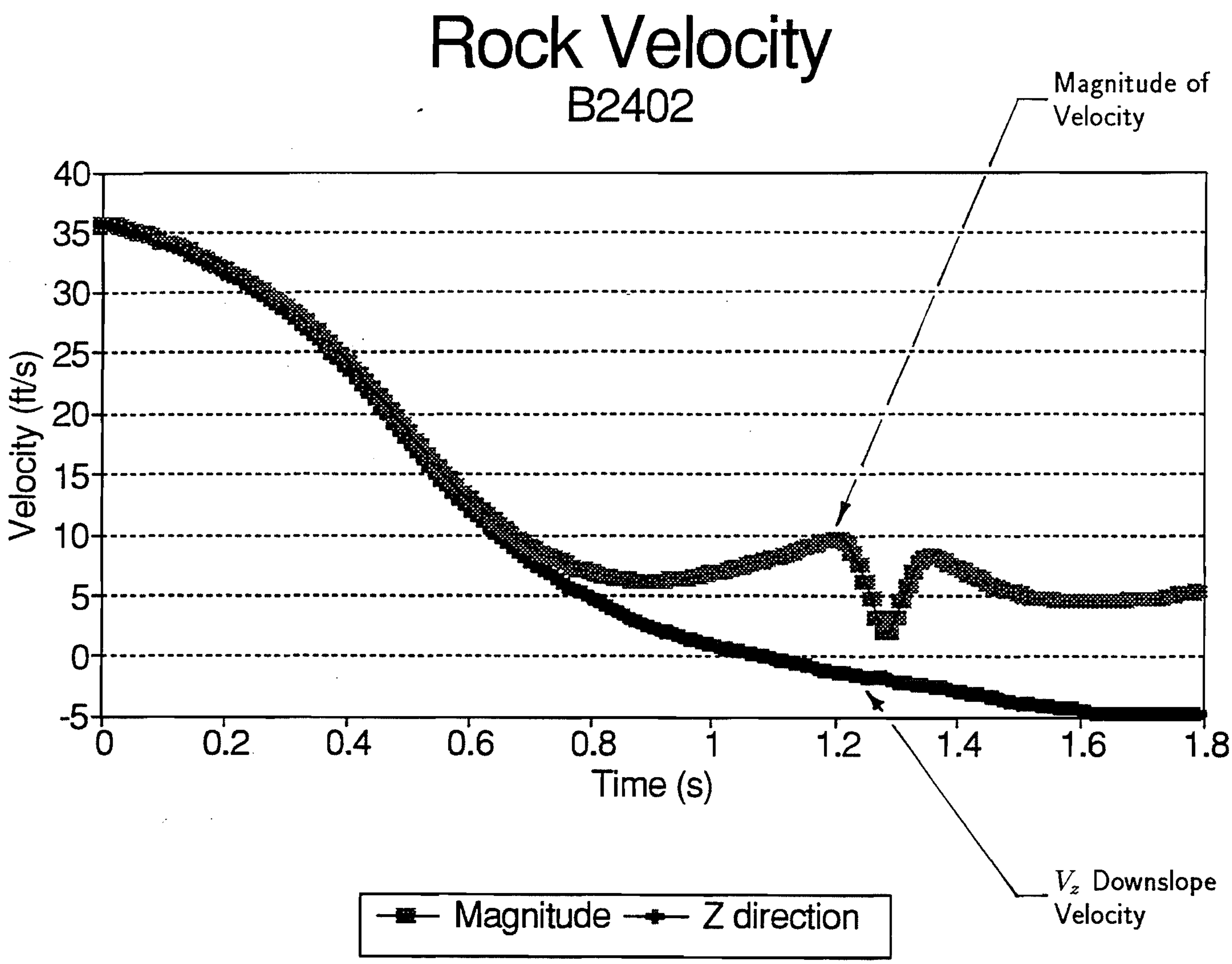


Figure III - 98
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model B

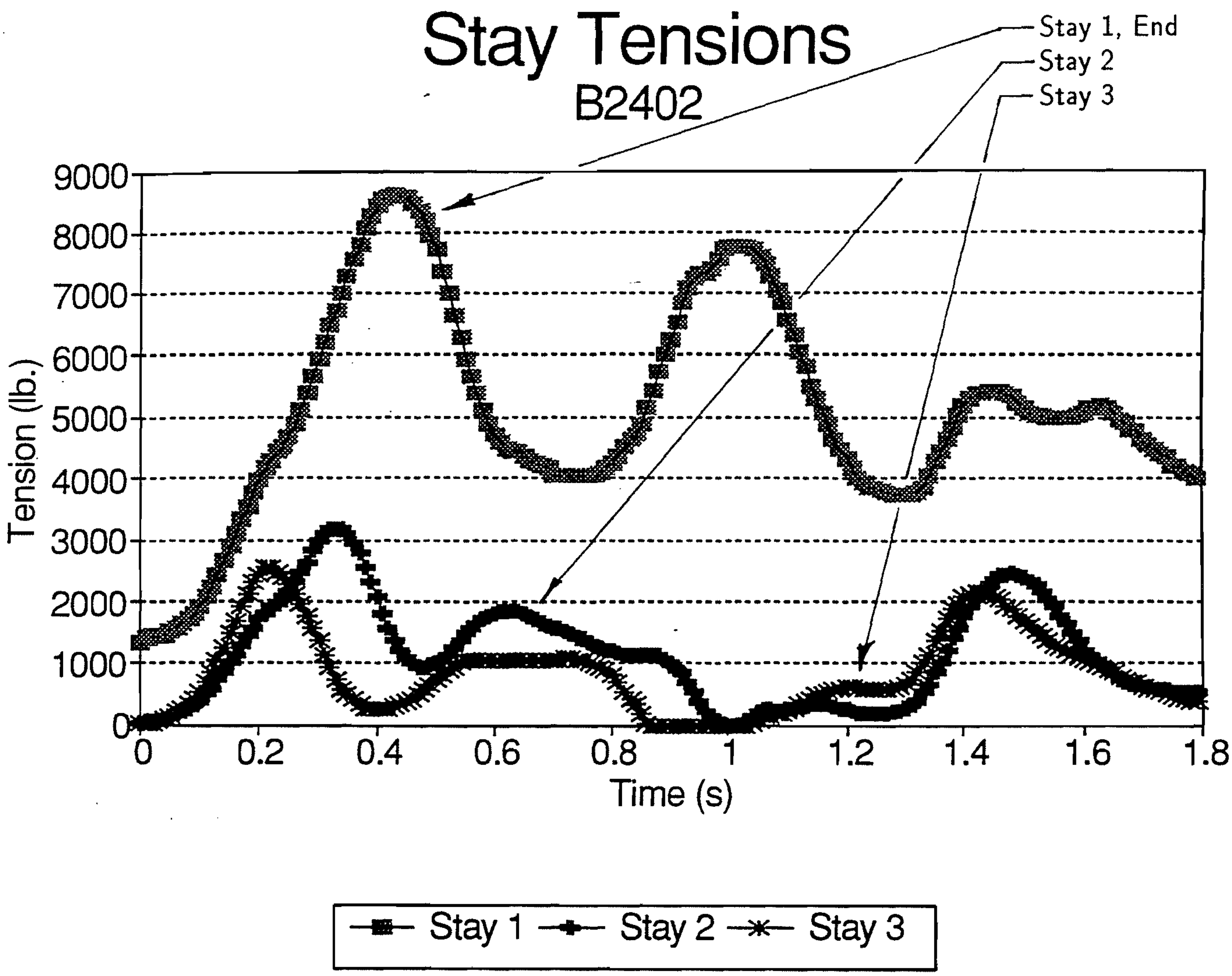


Figure III - 99
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model B

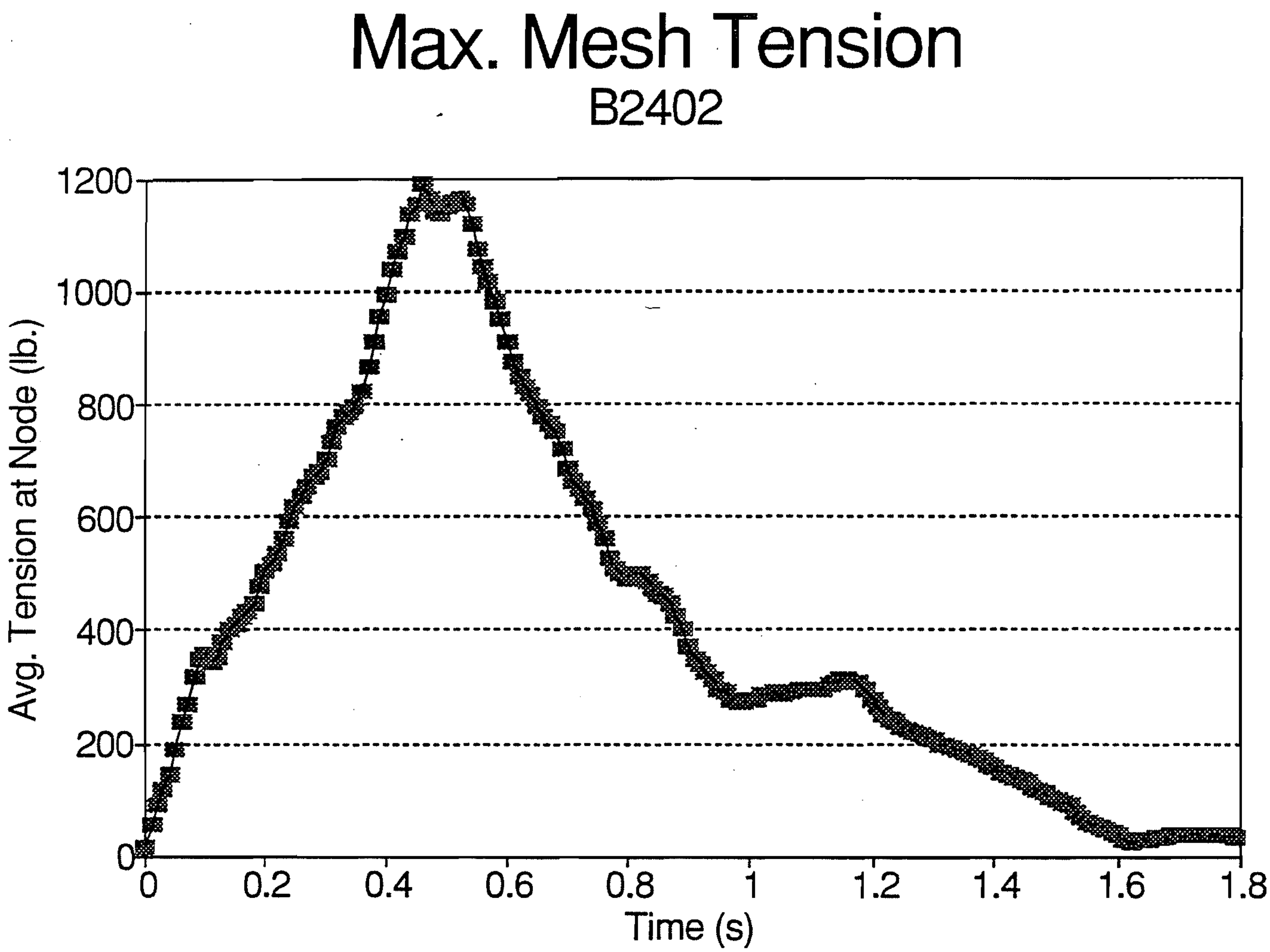


Figure III - 100
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model B

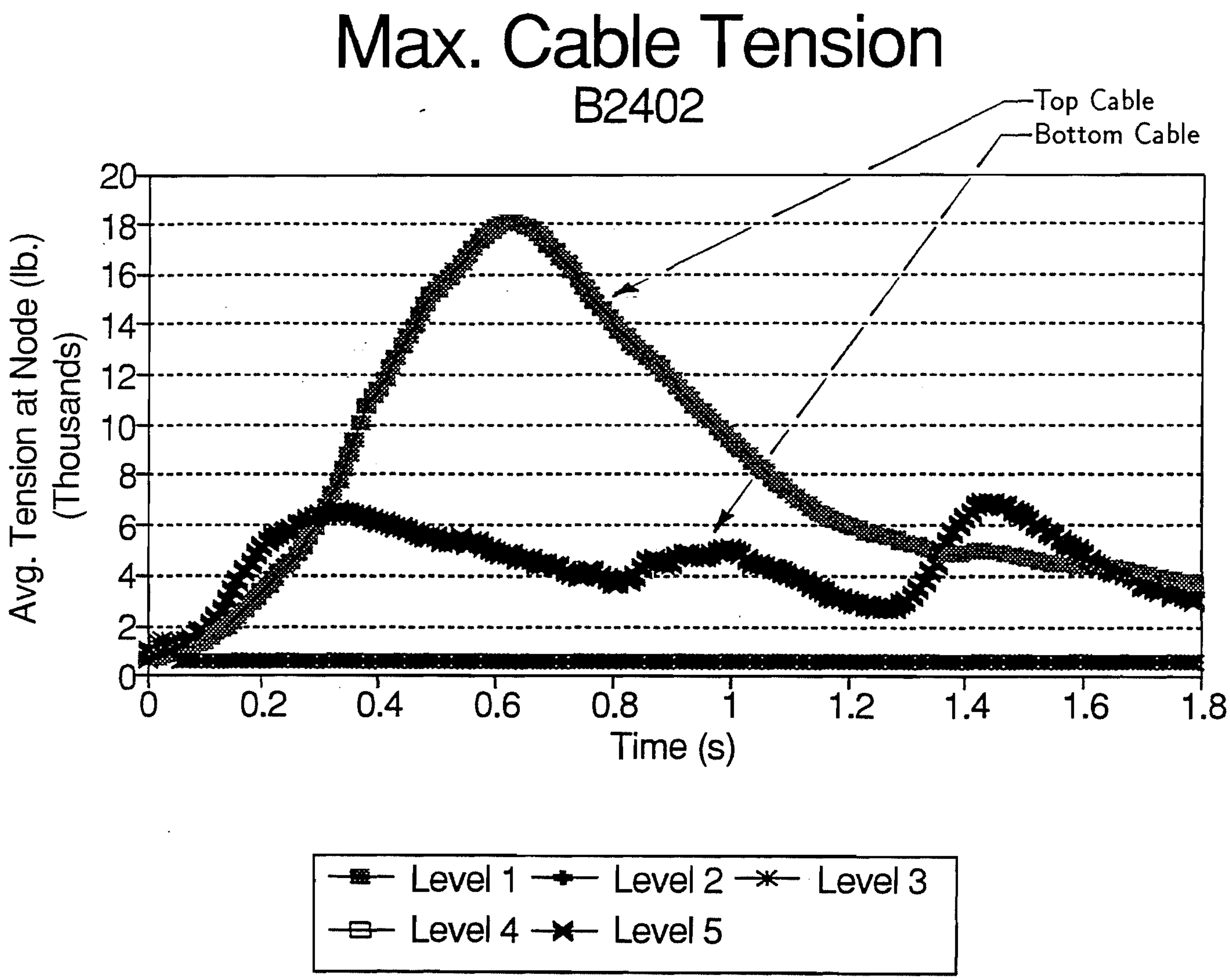
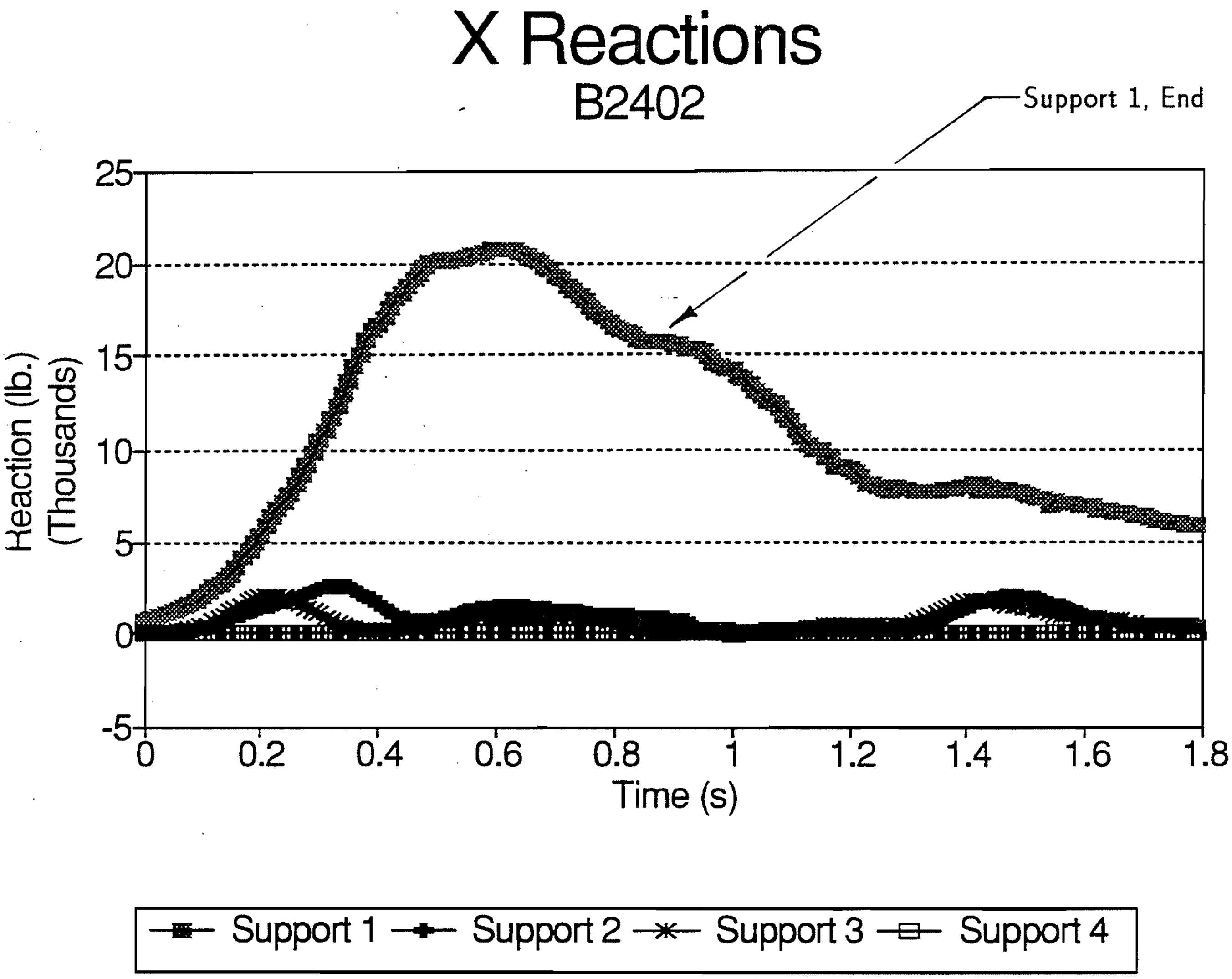
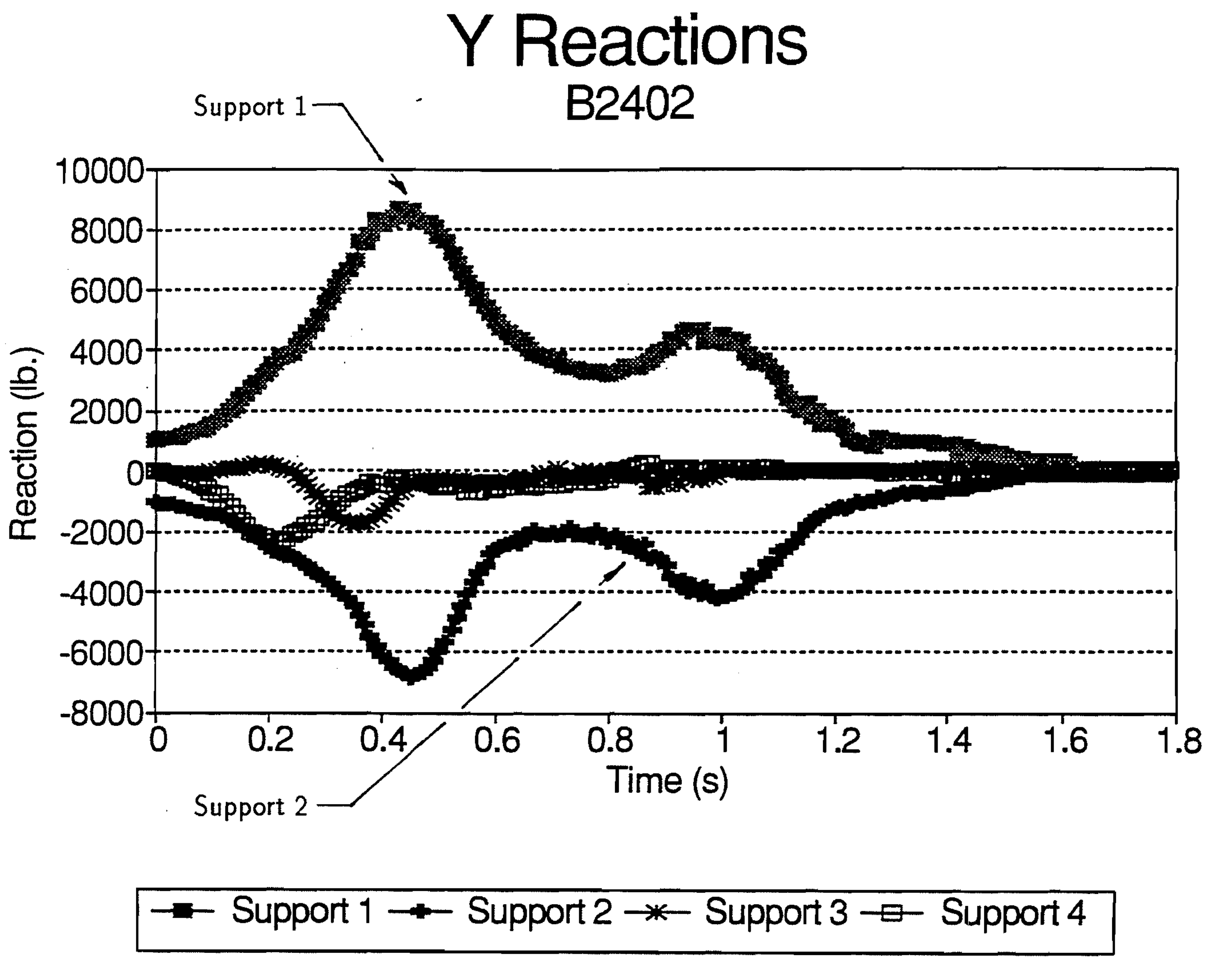


Figure III - 101
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model B



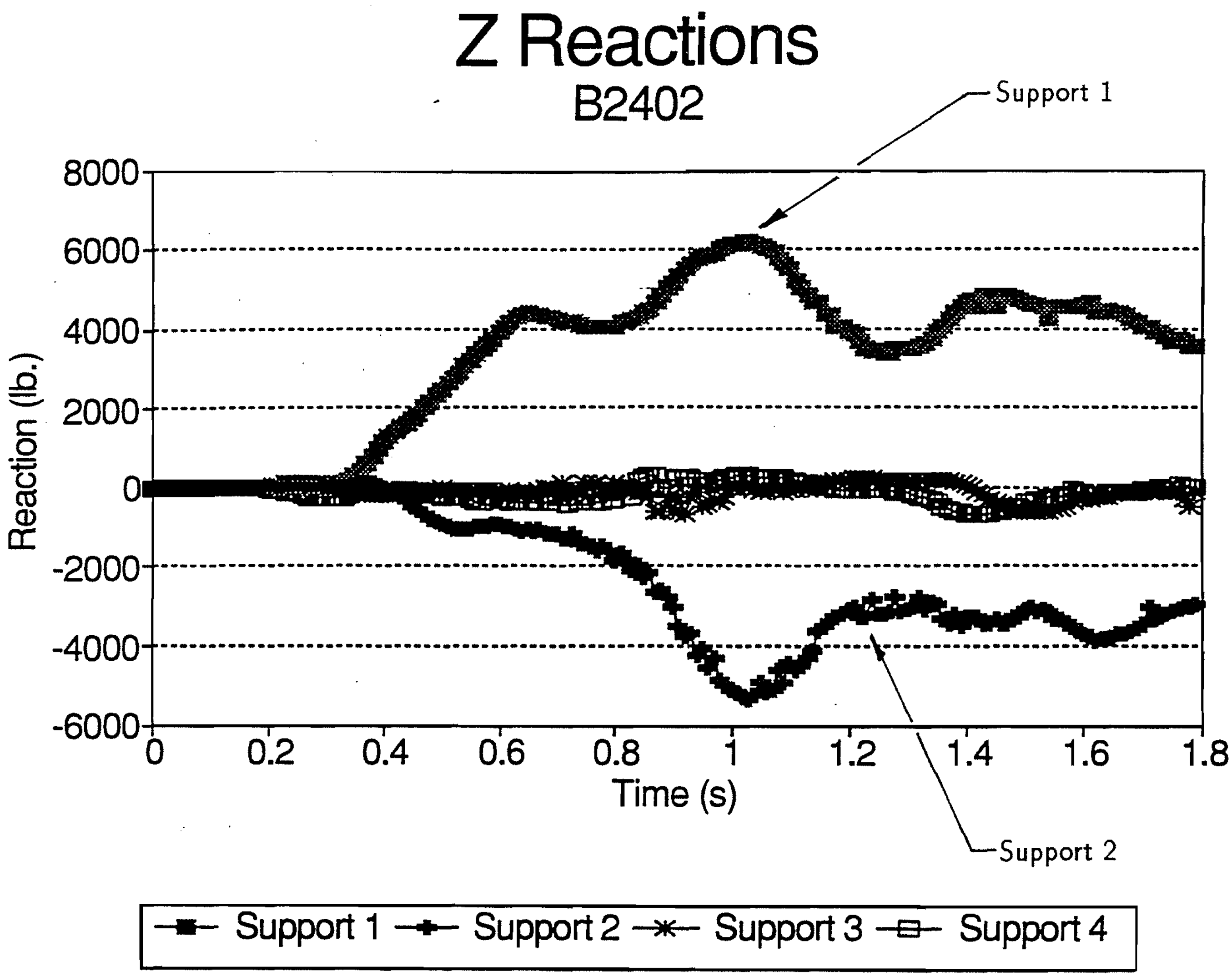
X Reaction, in-plane

Figure III - 102
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model B



Y Reaction, Vertical

Figure III - 103
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model B



Z Reaction, Downslope

Figure III - 104
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model B

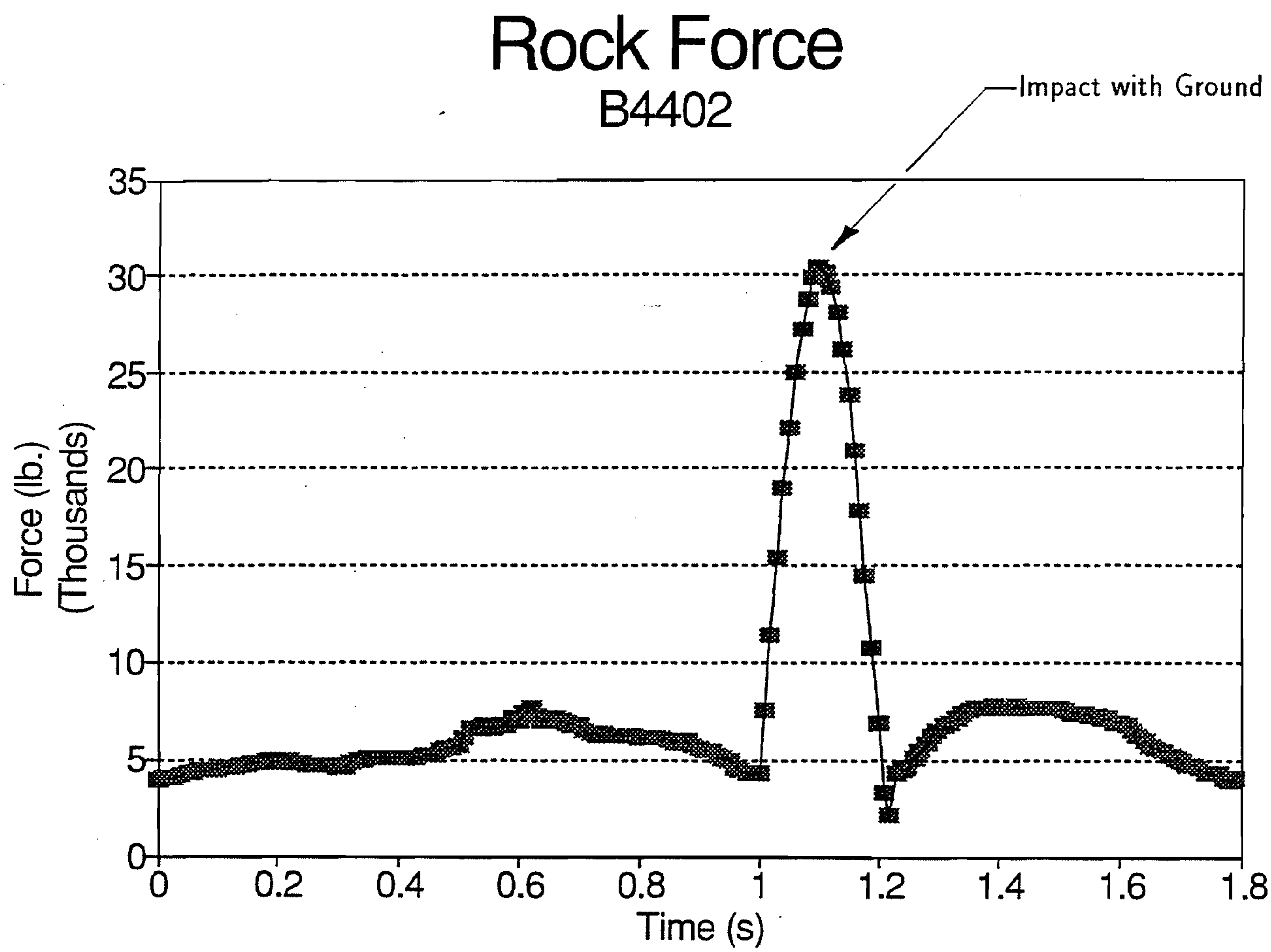


Figure III - 105
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model B

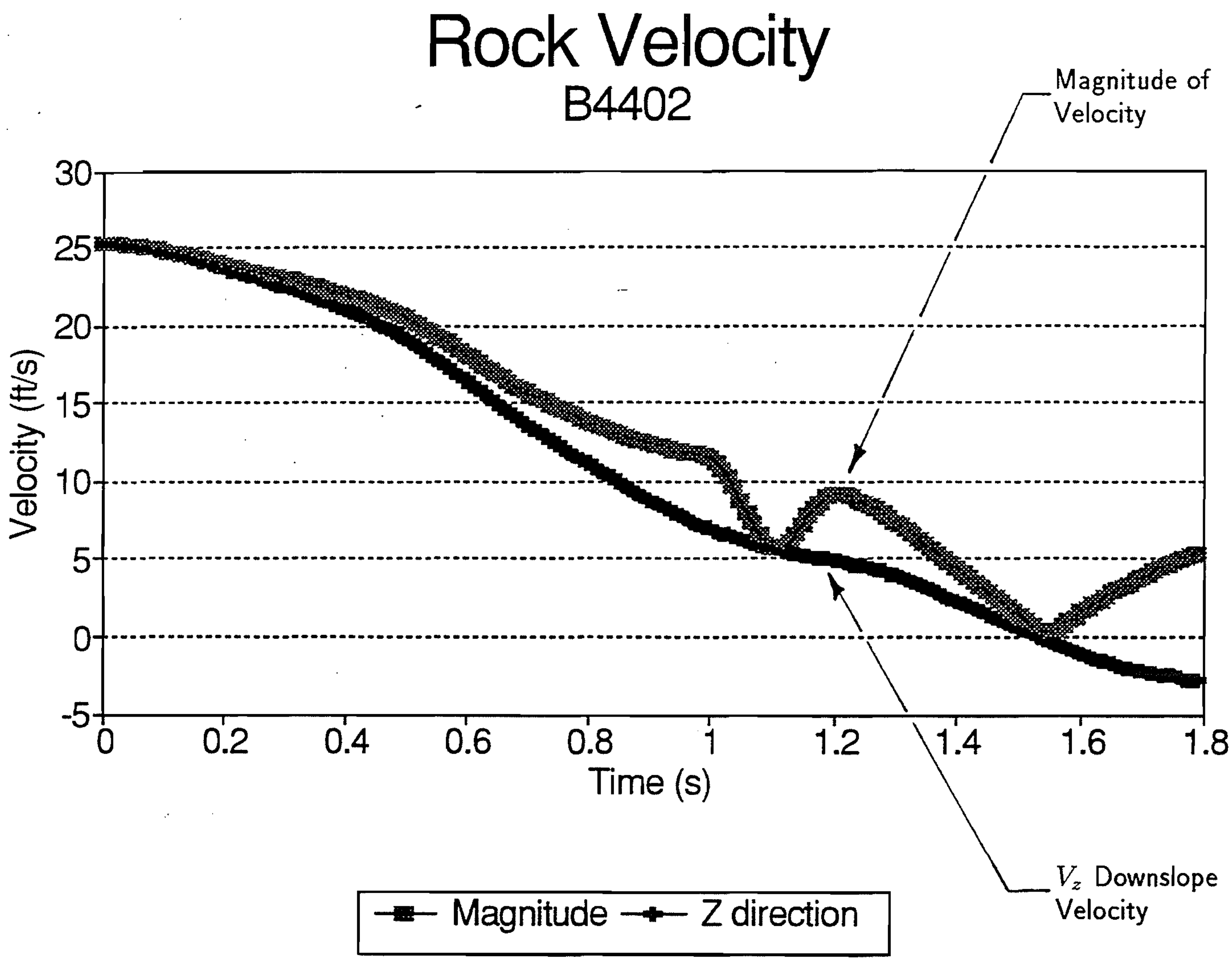


Figure III - 106
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model B

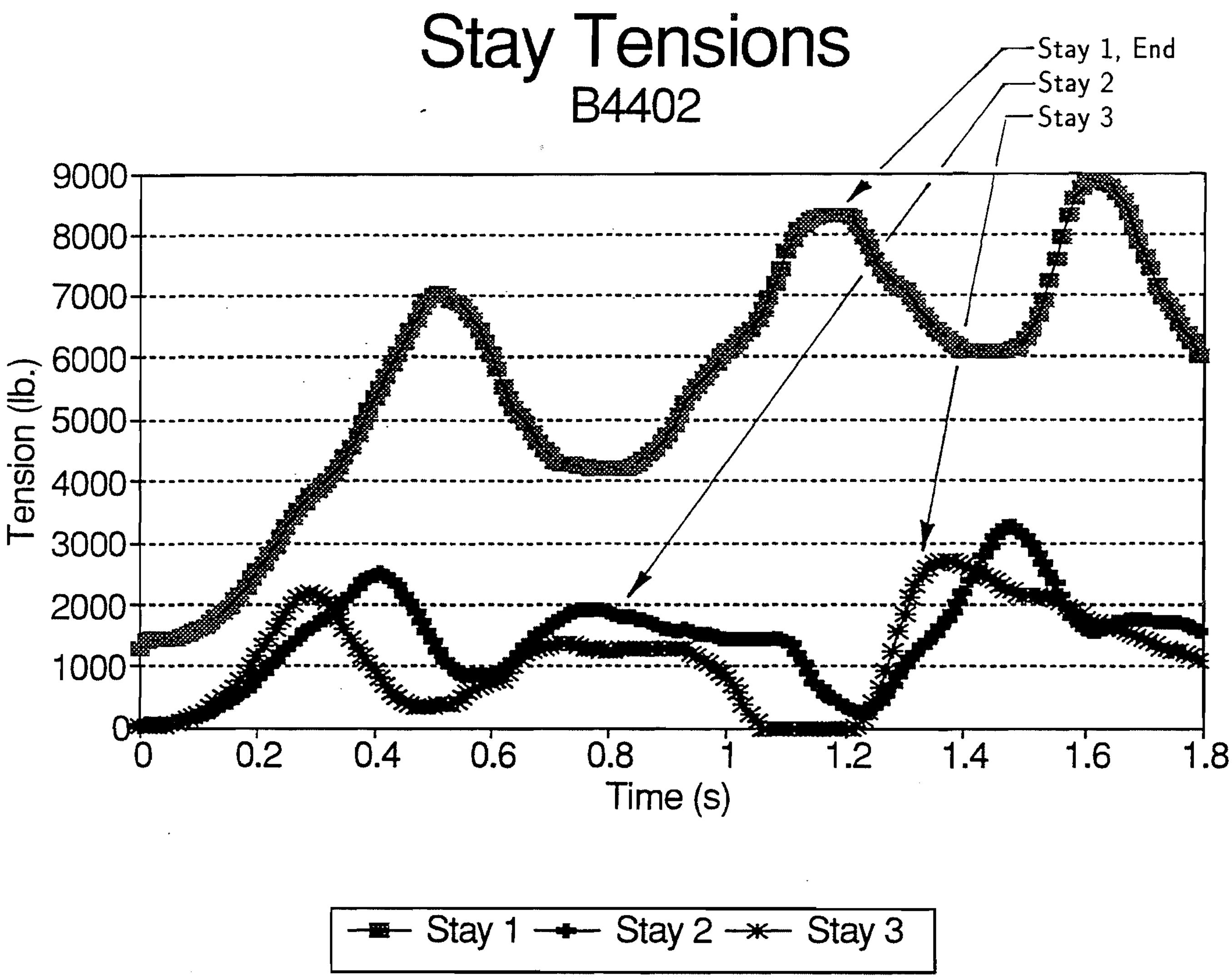


Figure III - 107
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model B

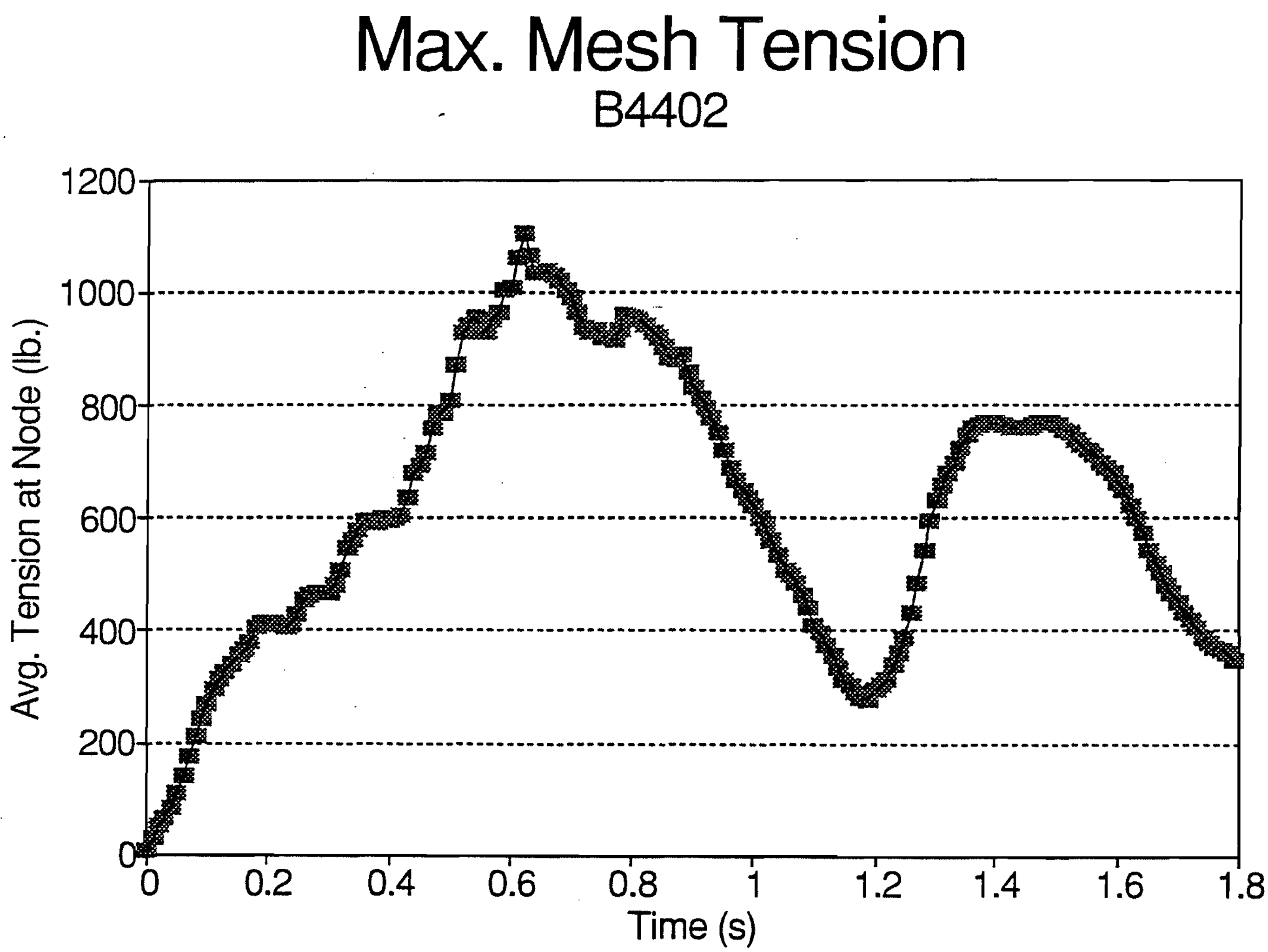


Figure III - 108
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model B

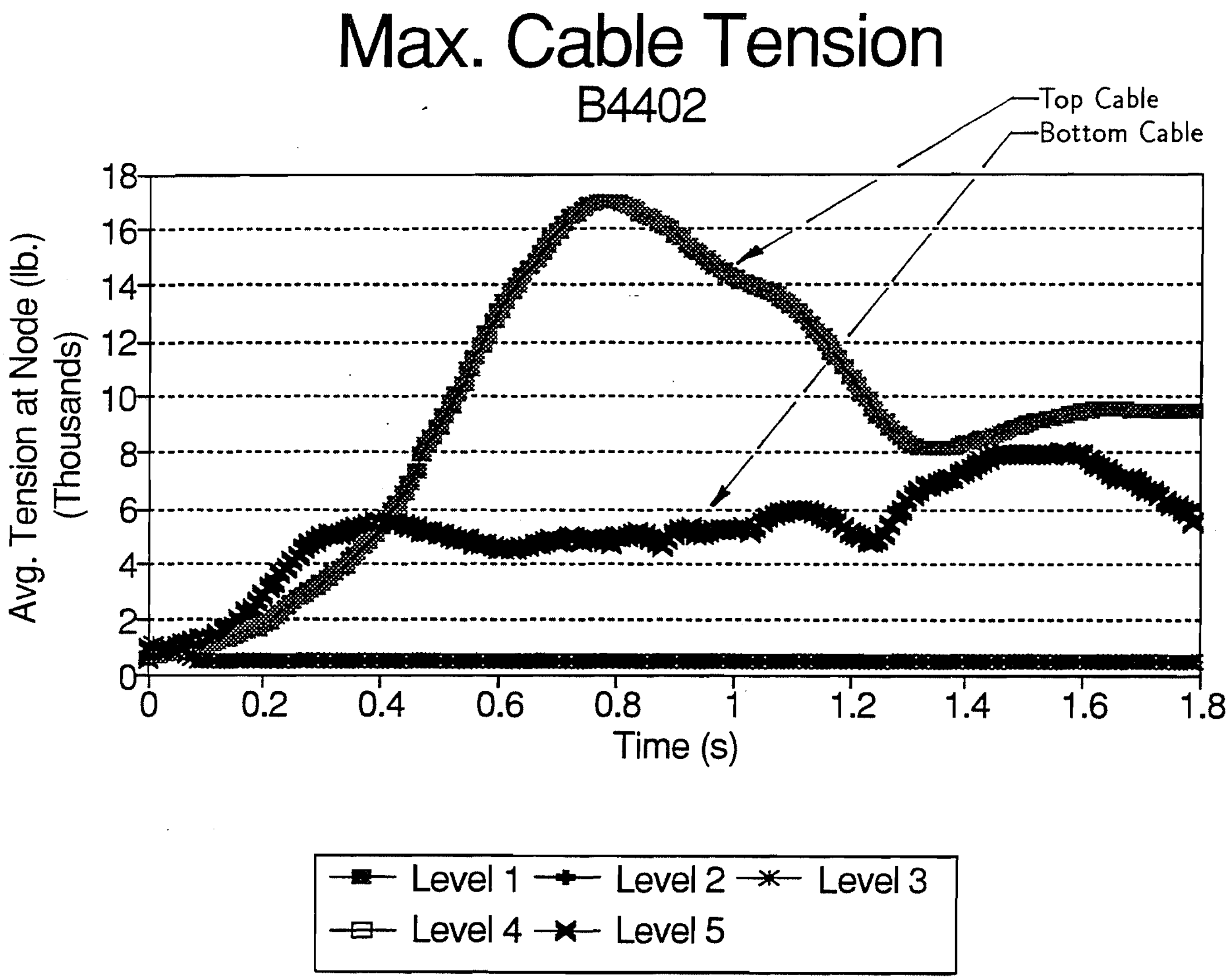
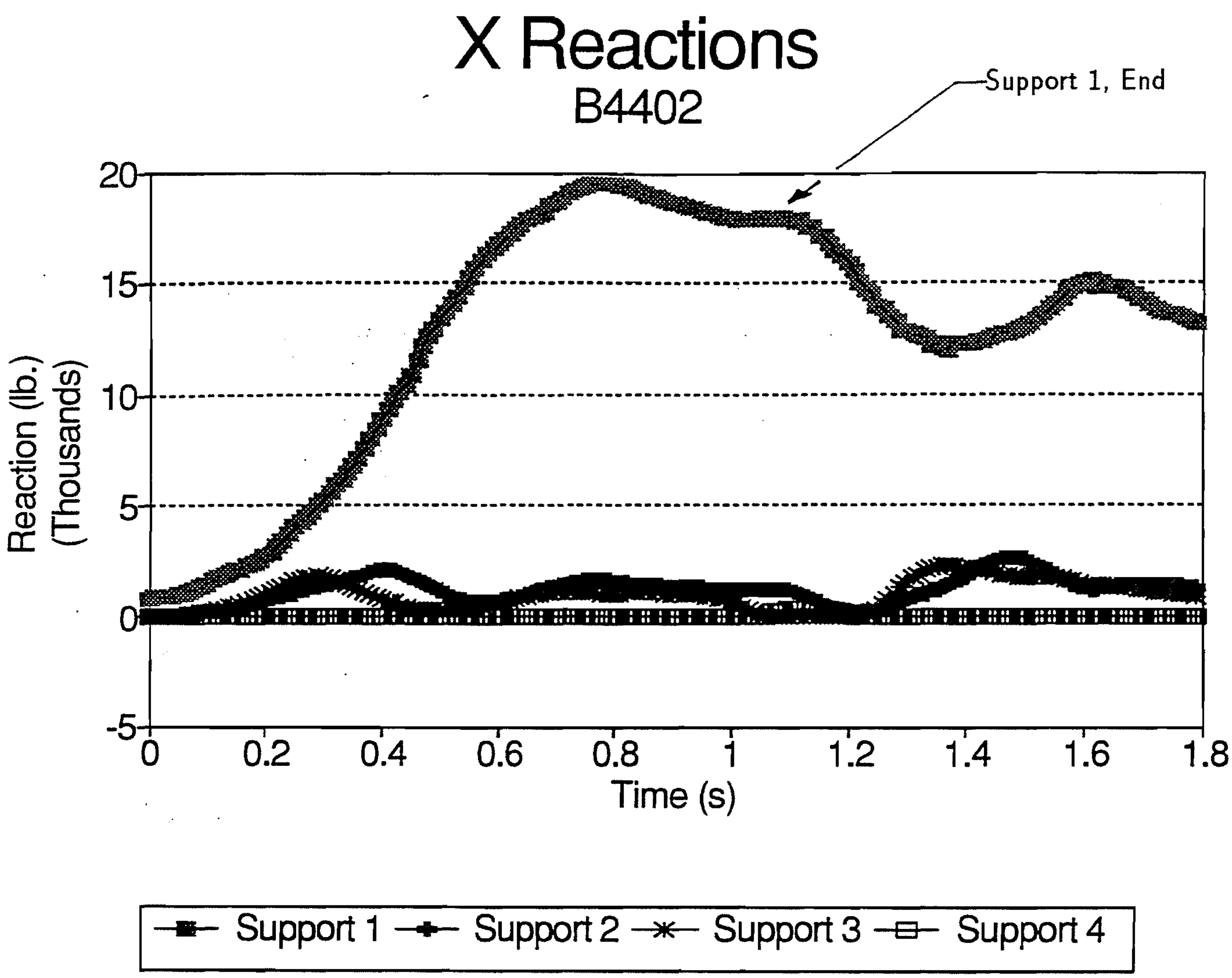
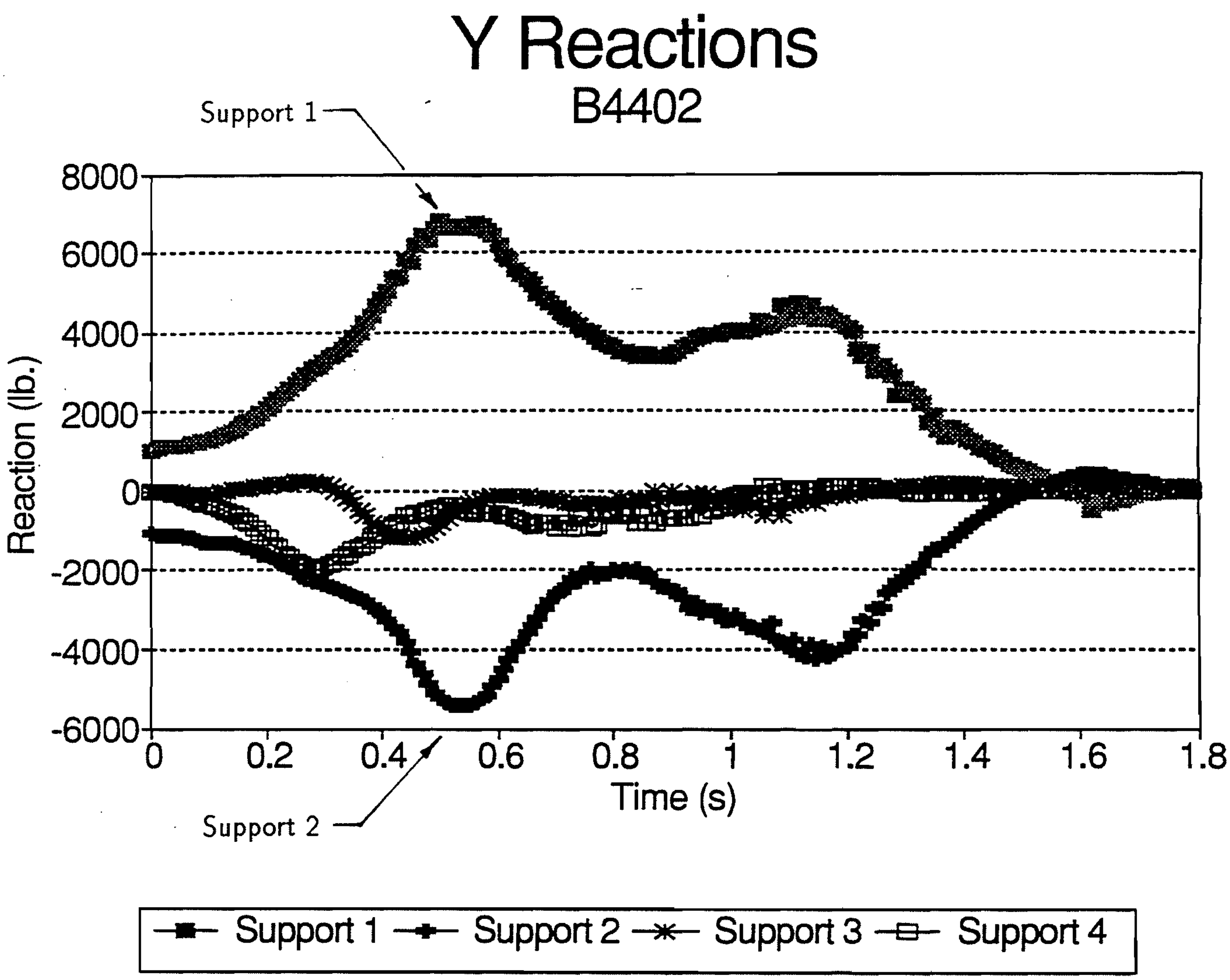


Figure III - 109
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model B



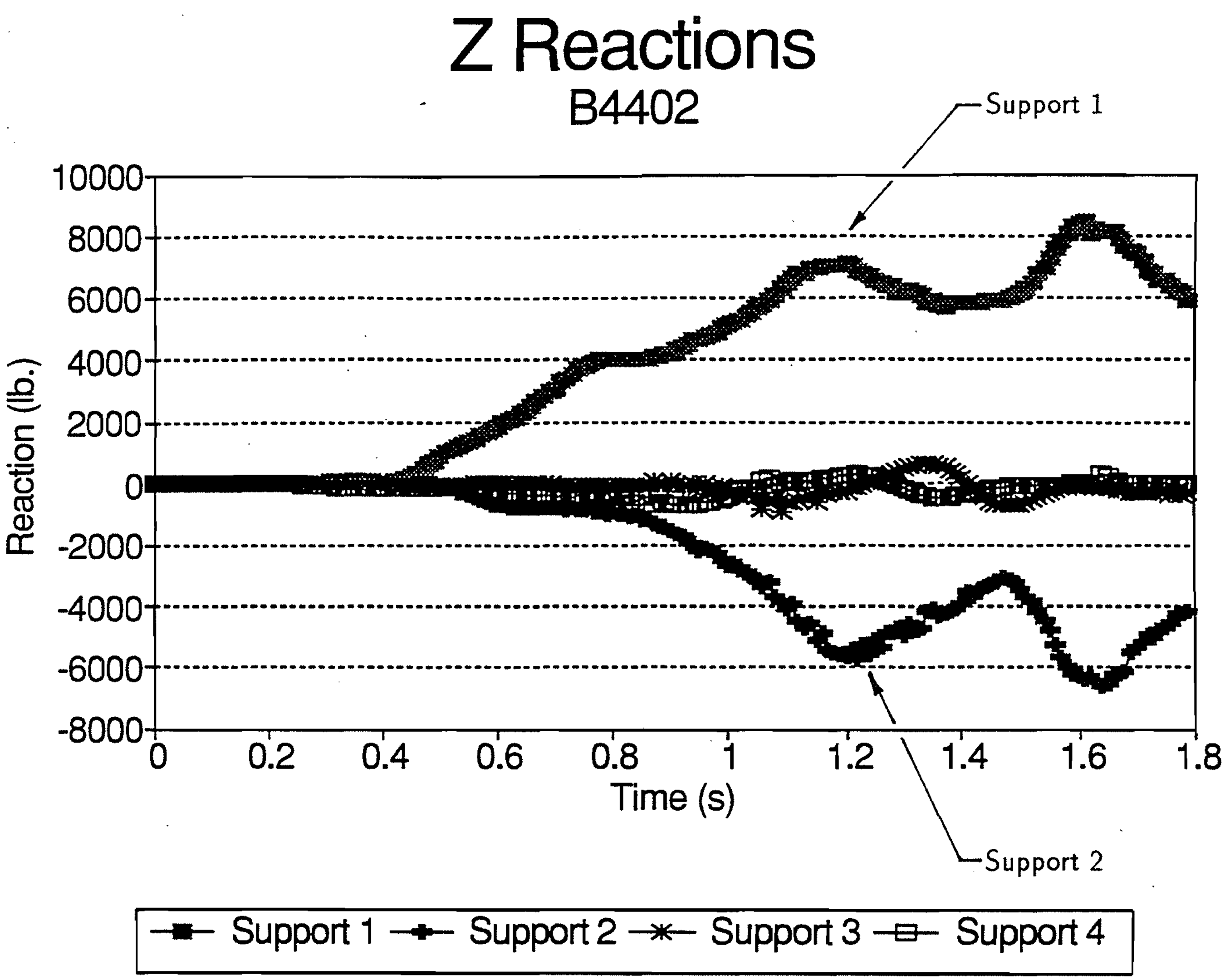
X Reaction, in-plane

Figure III - 110
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model B



Y Reaction, Vertical

Figure III - 111
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model B



Z Reaction, Downslope

Figure III - 112
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model B

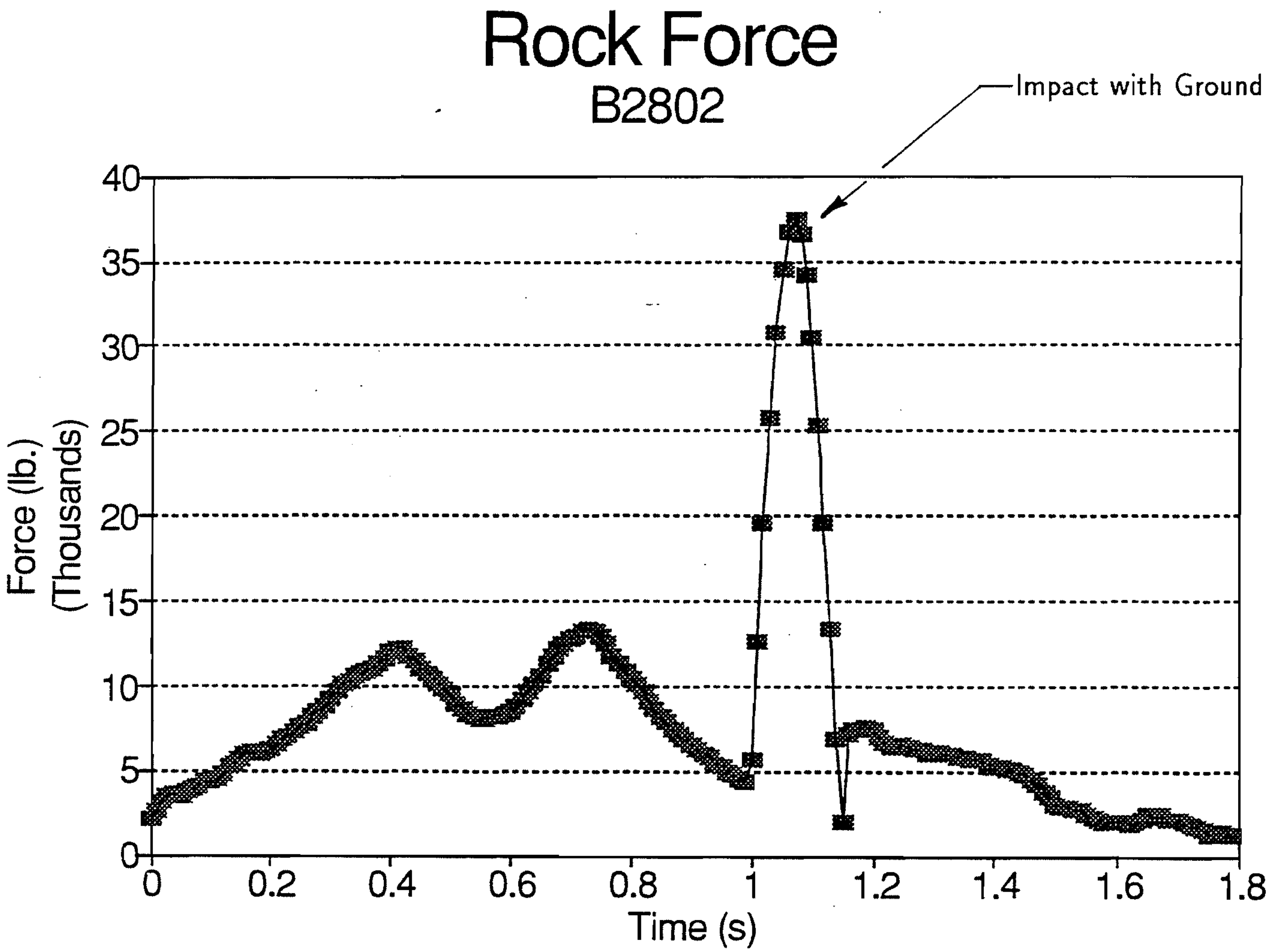


Figure III - 113
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model B

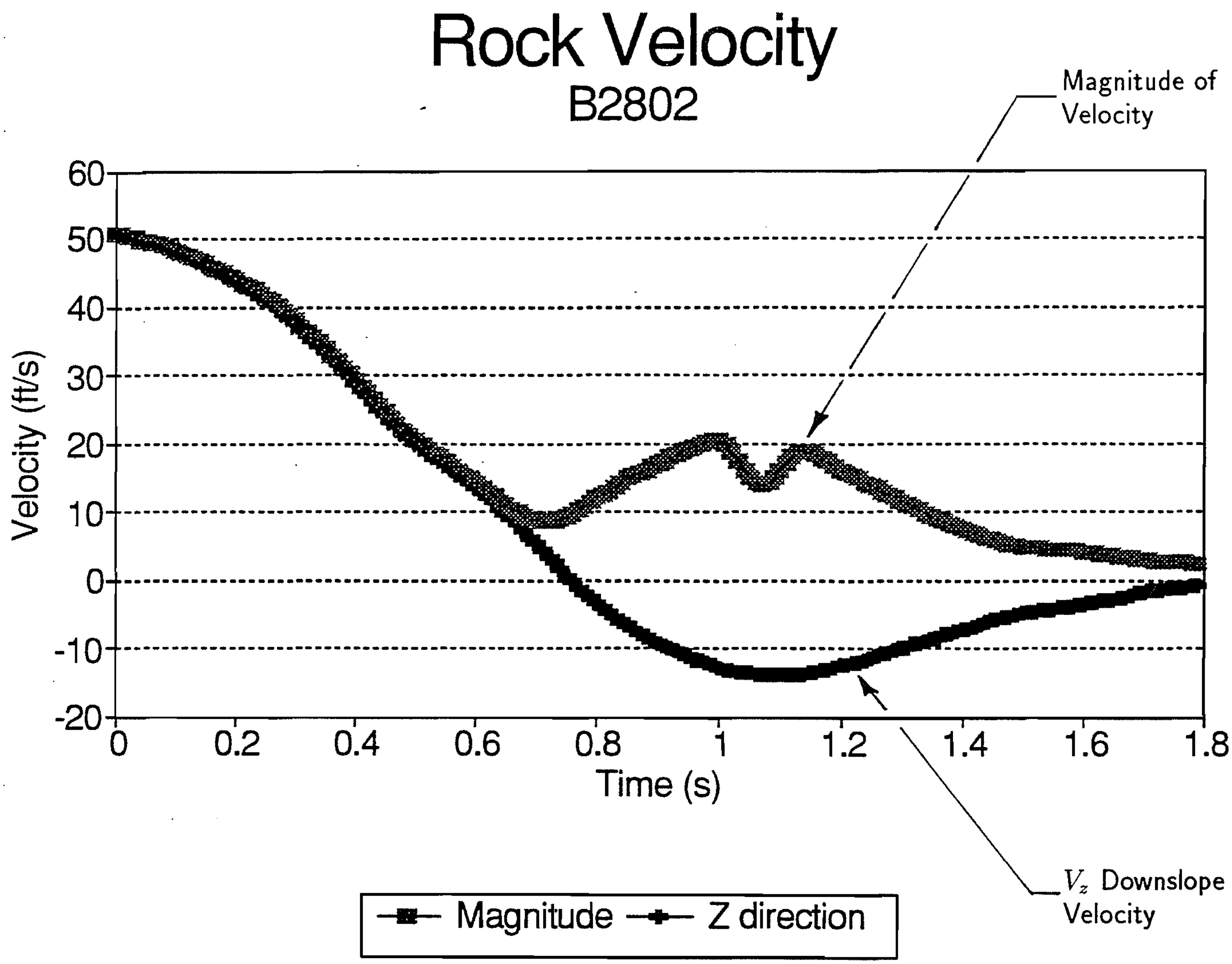


Figure III - 114
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model B

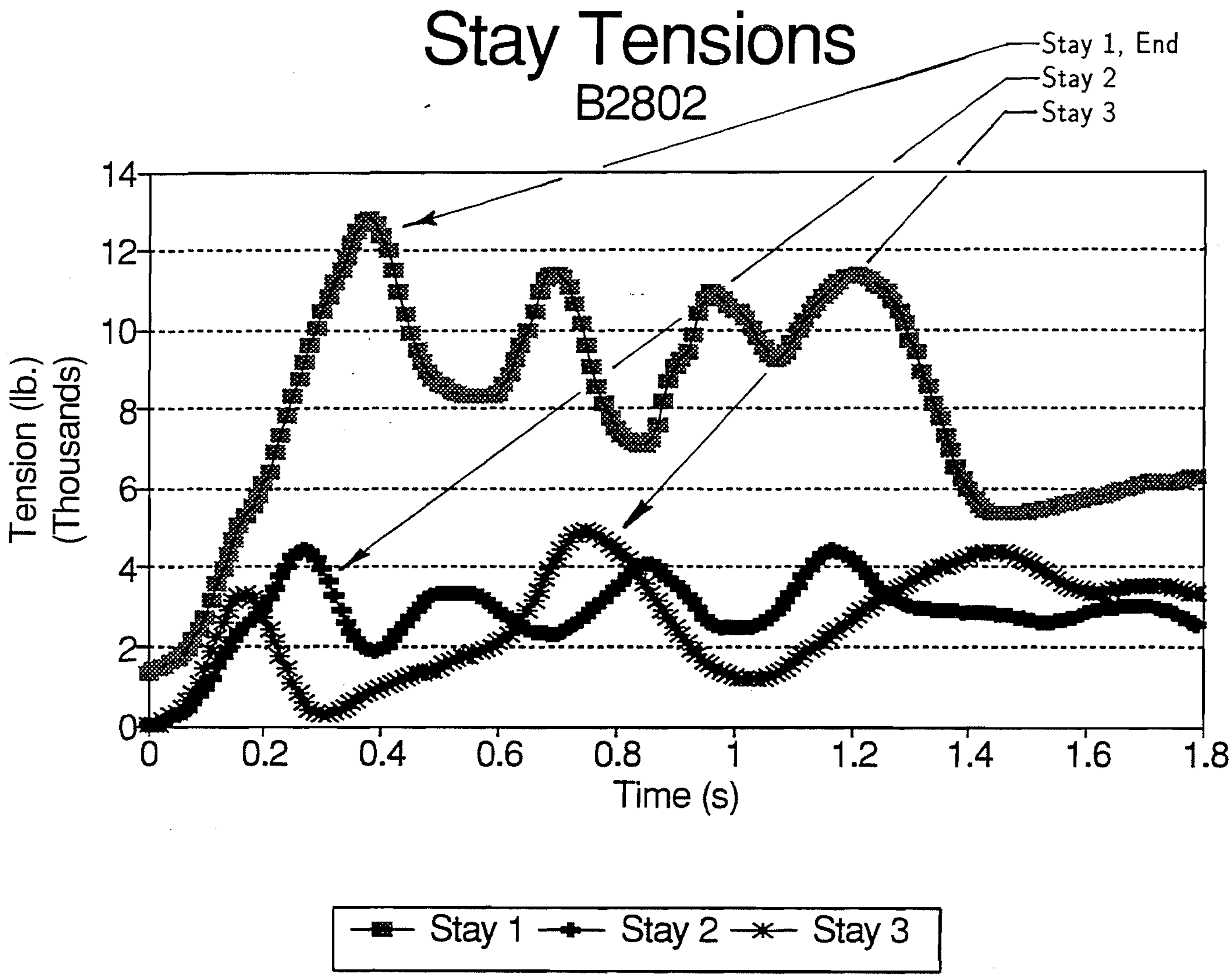


Figure III - 115
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model B

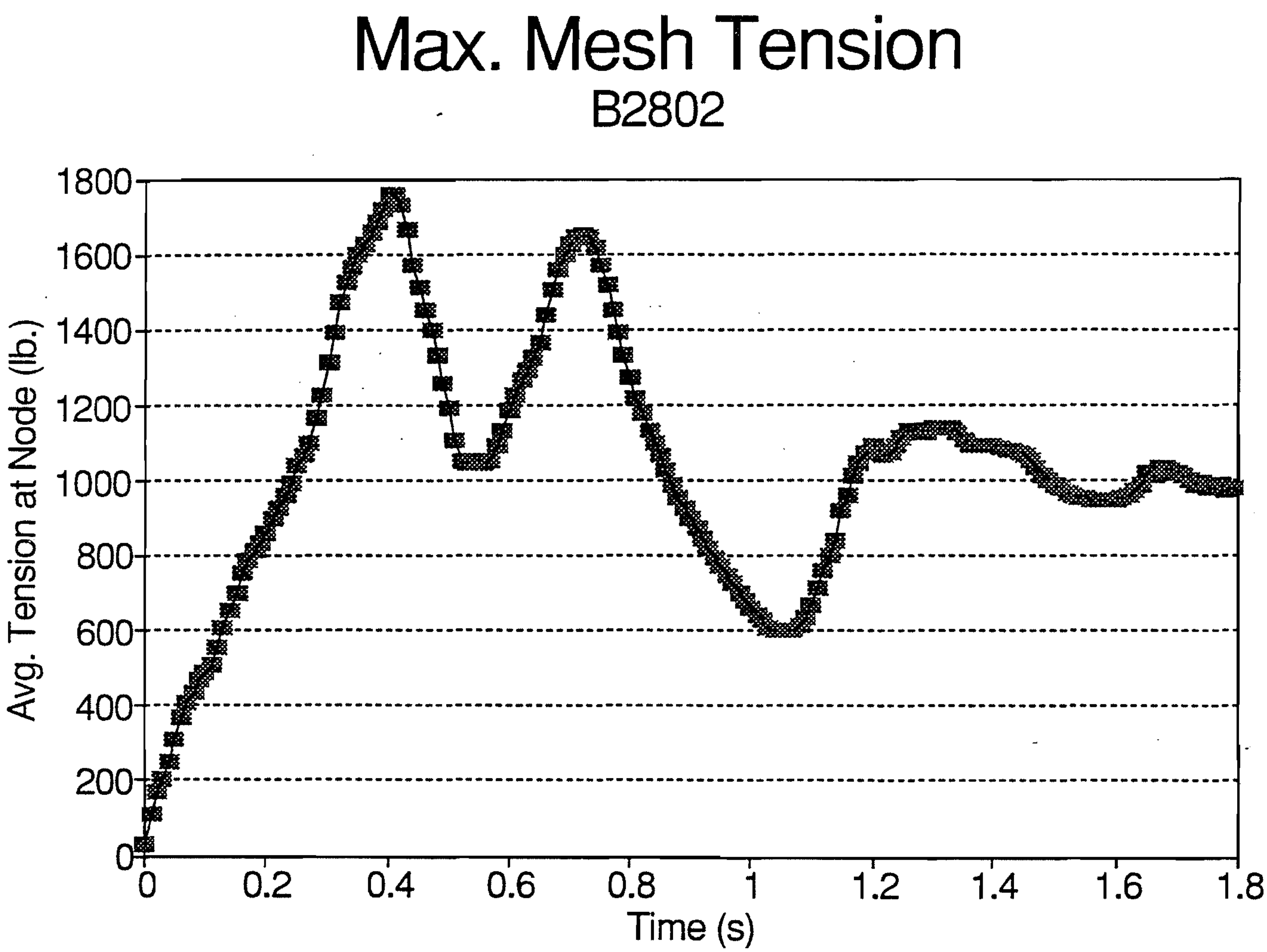


Figure III - 116
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model B

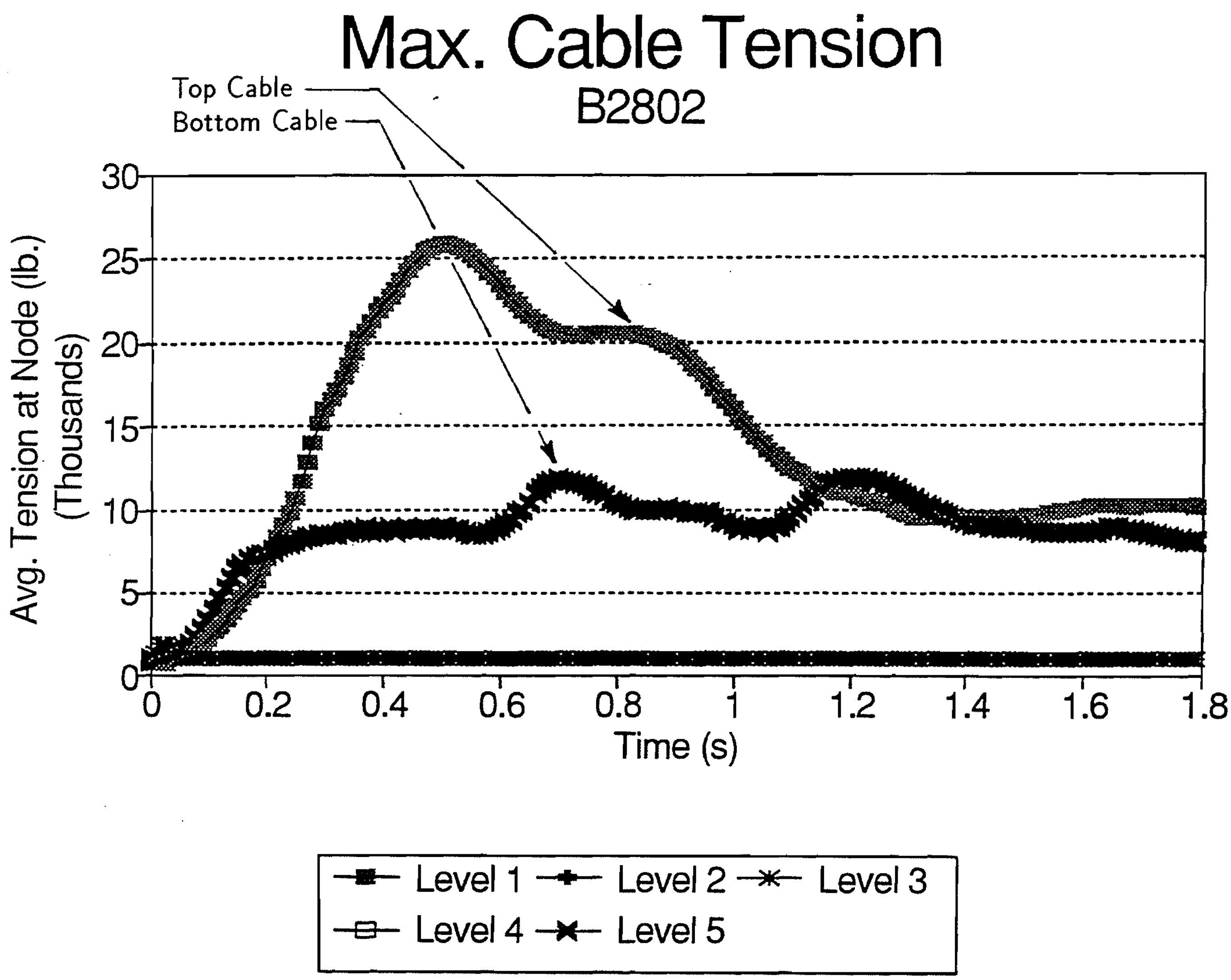
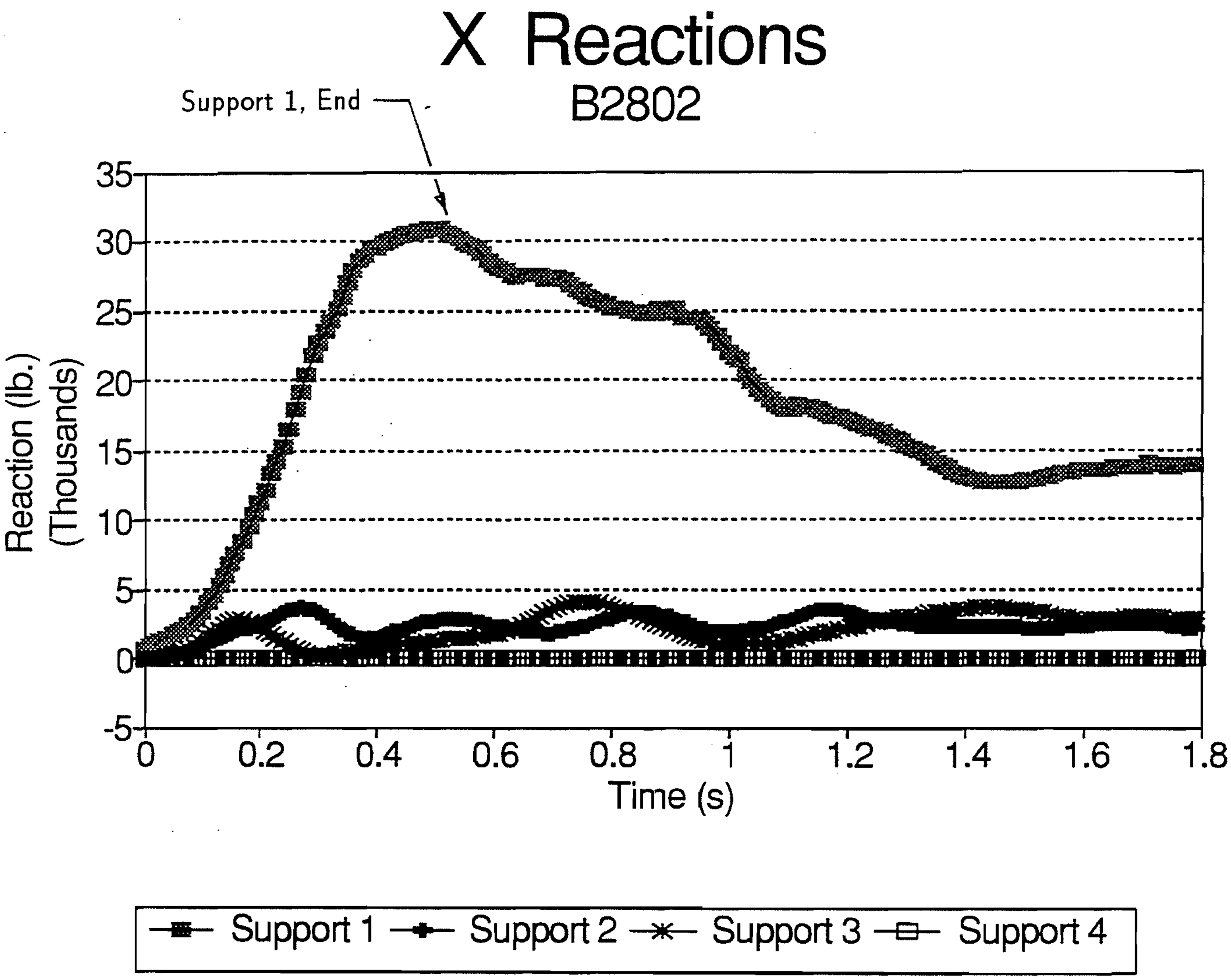
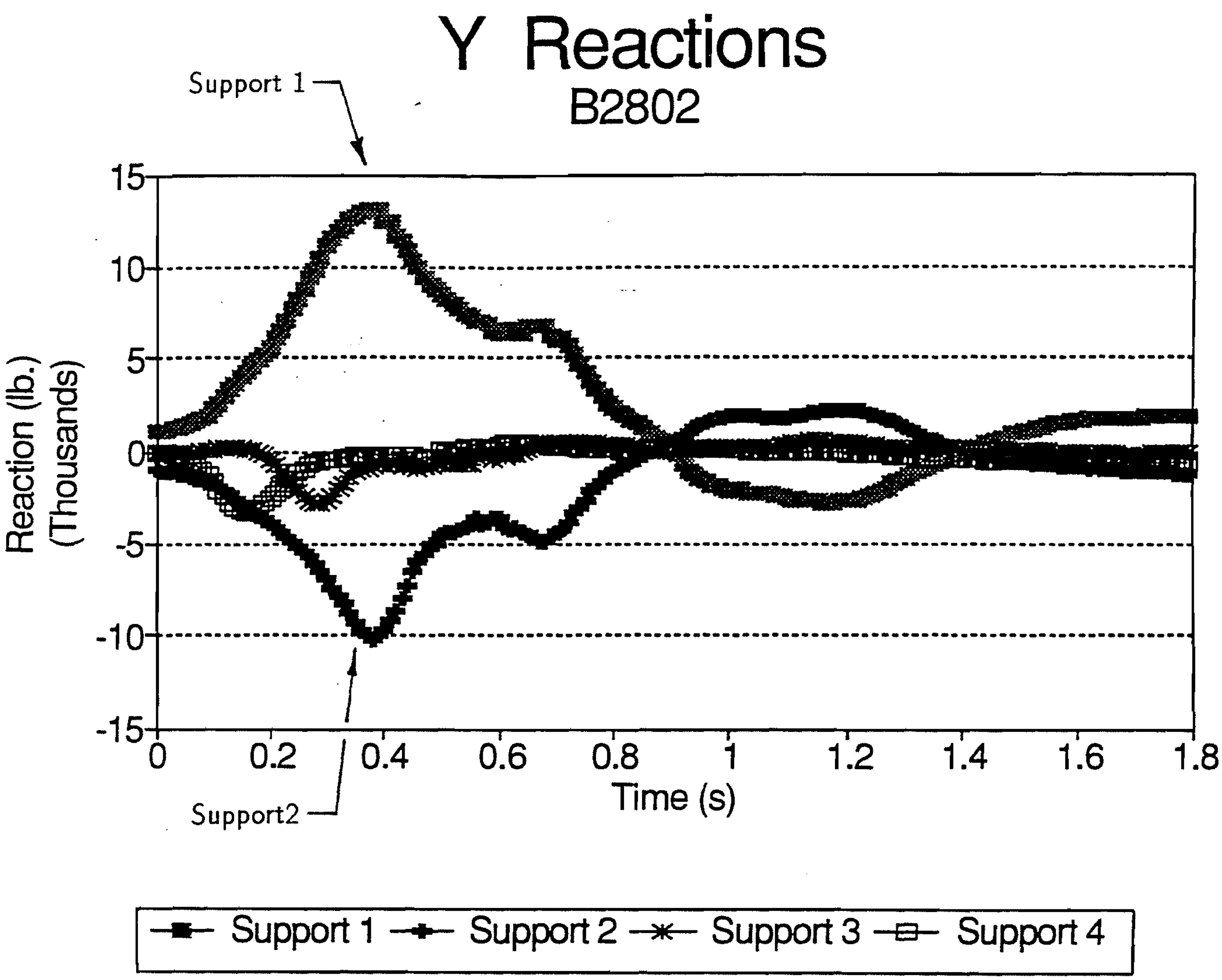


Figure III - 117
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model B



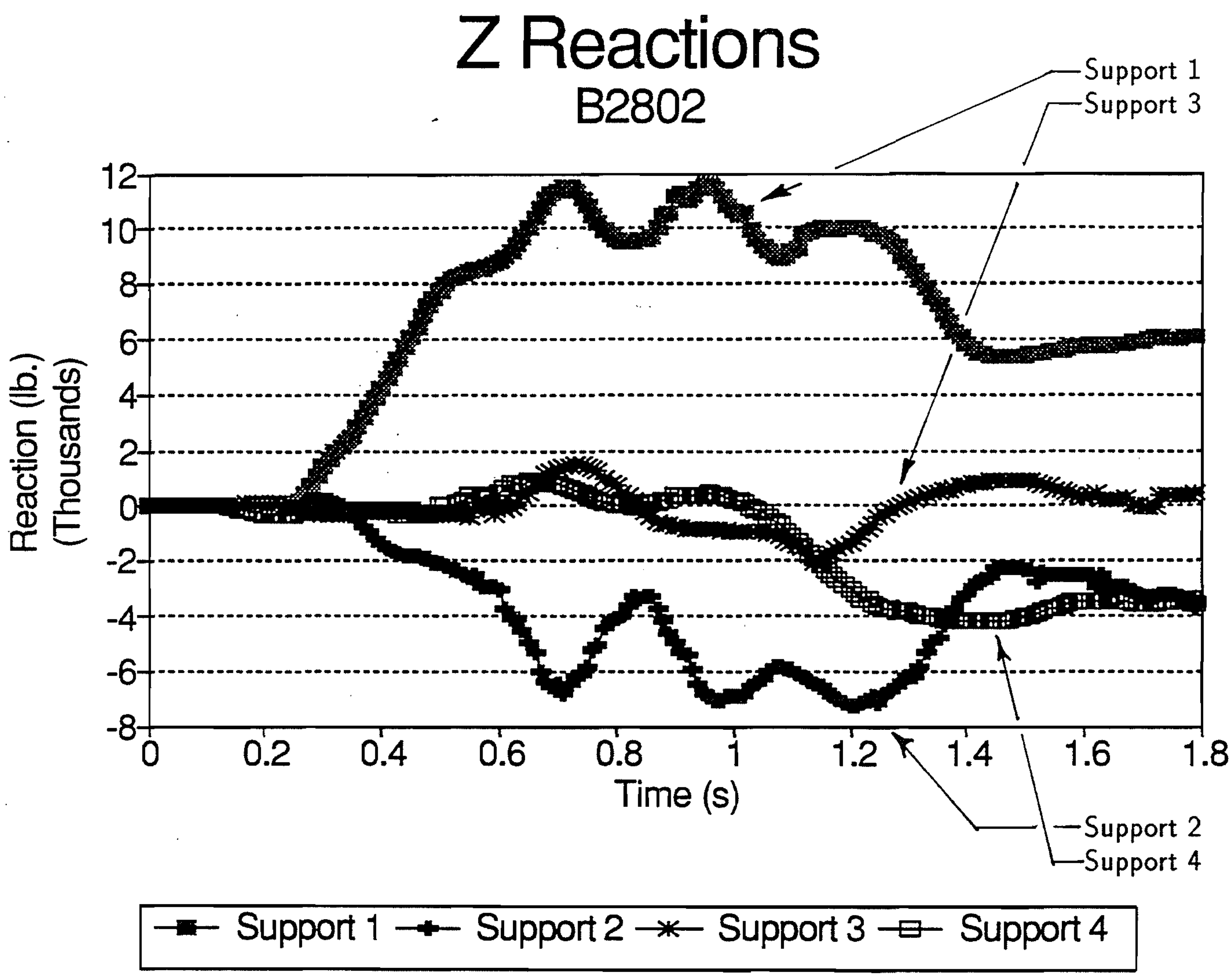
X Reaction, in-plane

Figure III - 118
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model B



Y Reaction, Vertical

Figure III - 119
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model A.T



Z Reaction, Downslope

Figure III - 120
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model B

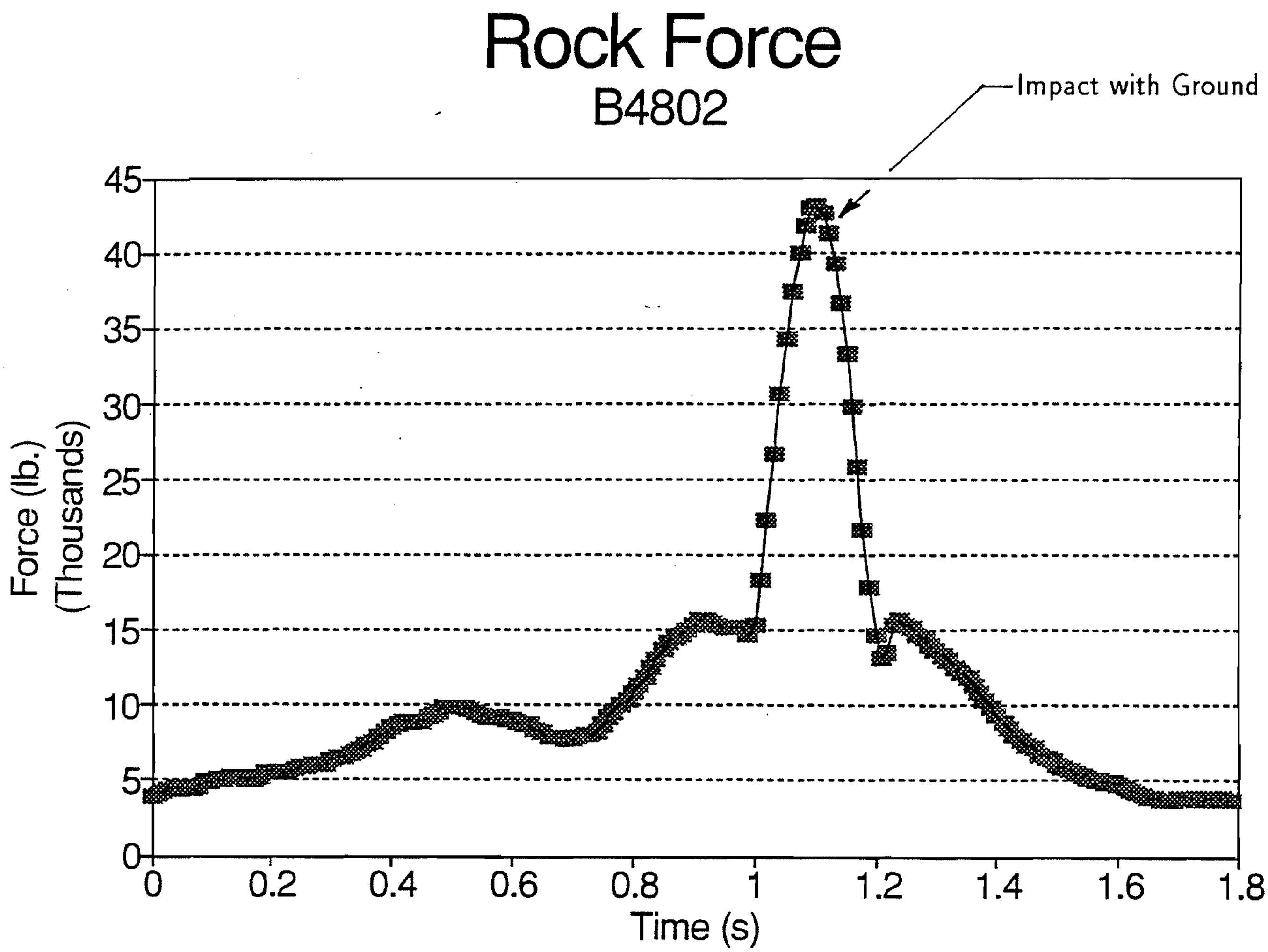


Figure III - 121
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model B

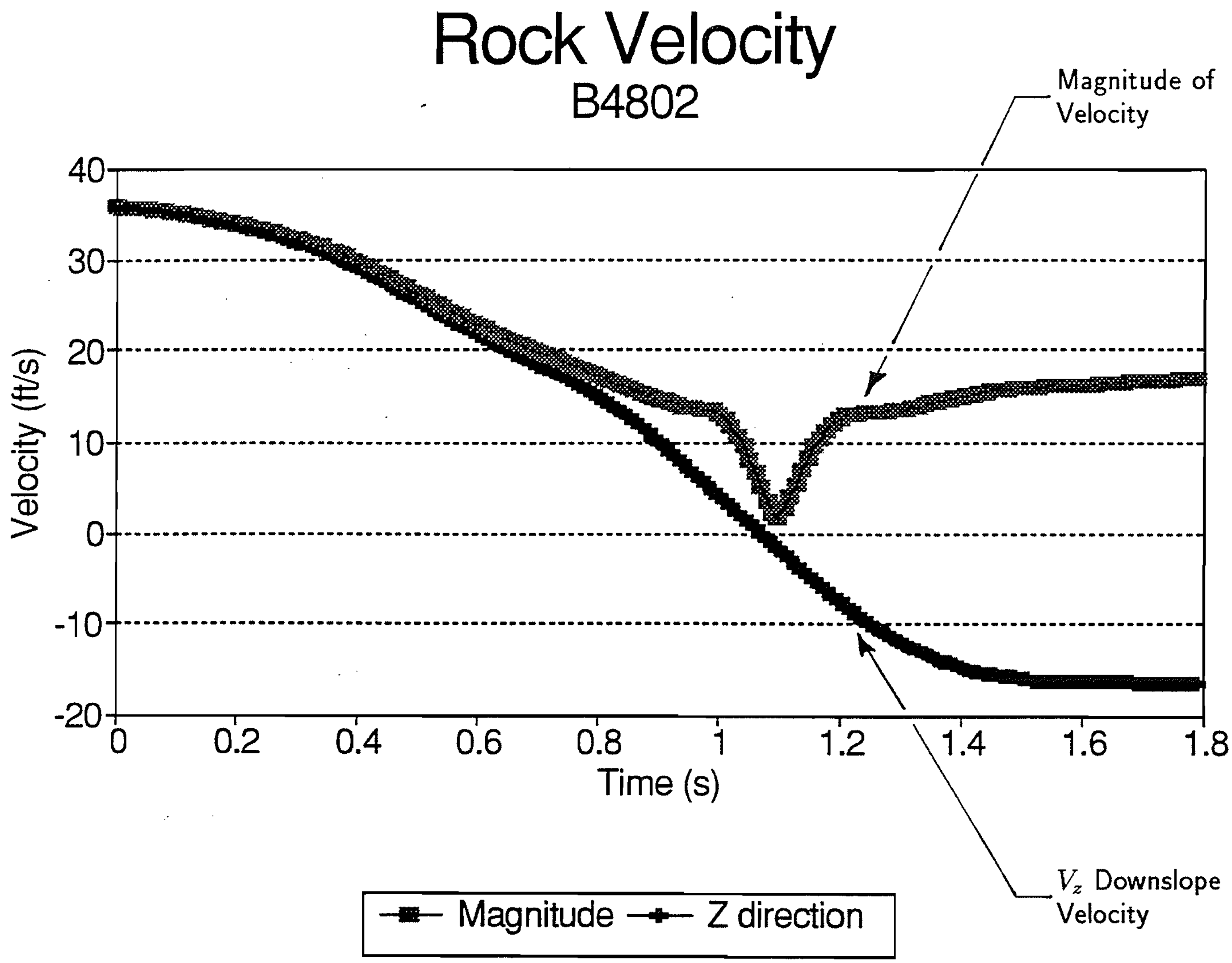


Figure III - 122
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model B

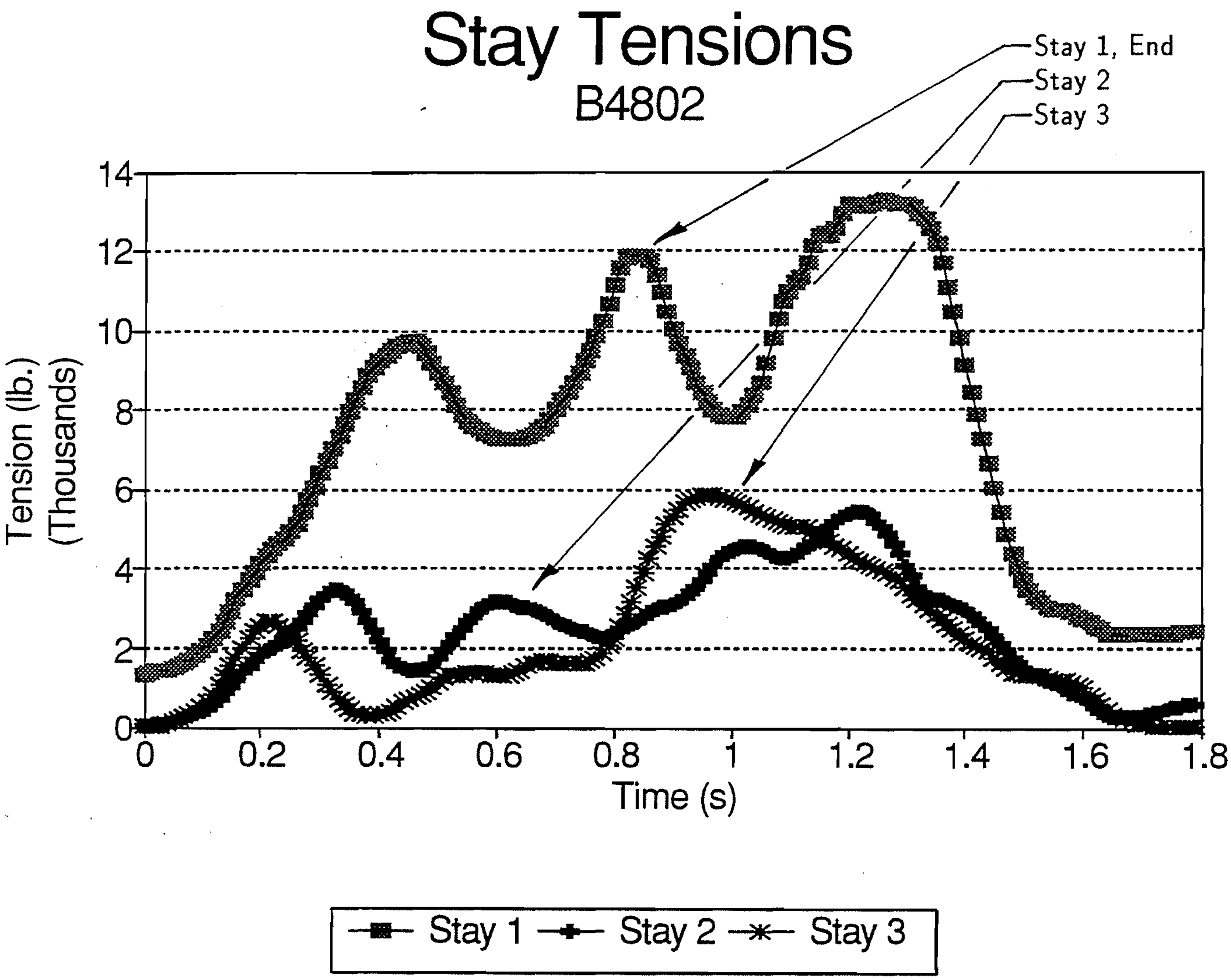


Figure III - 123
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model B

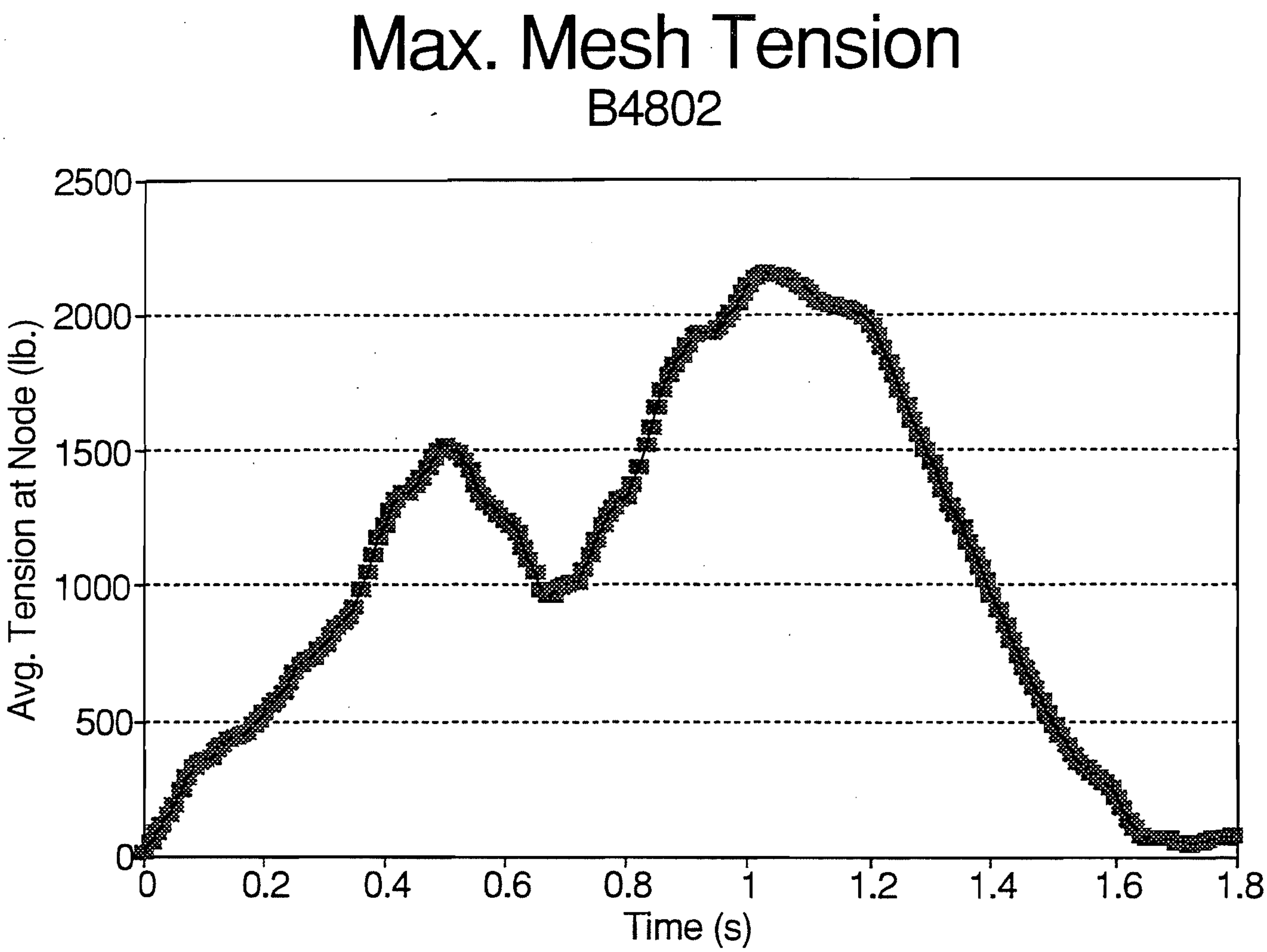


Figure III - 124
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model B

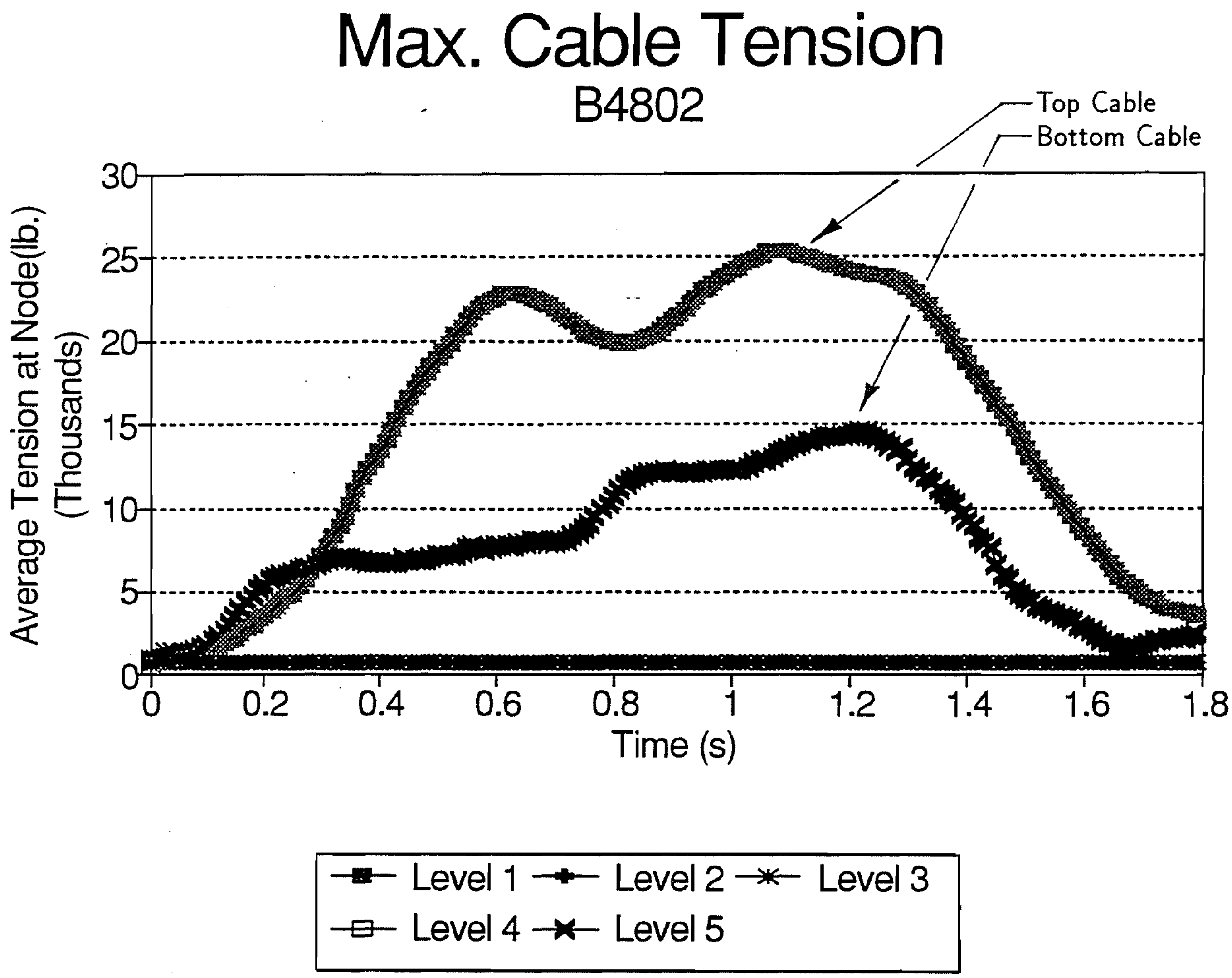
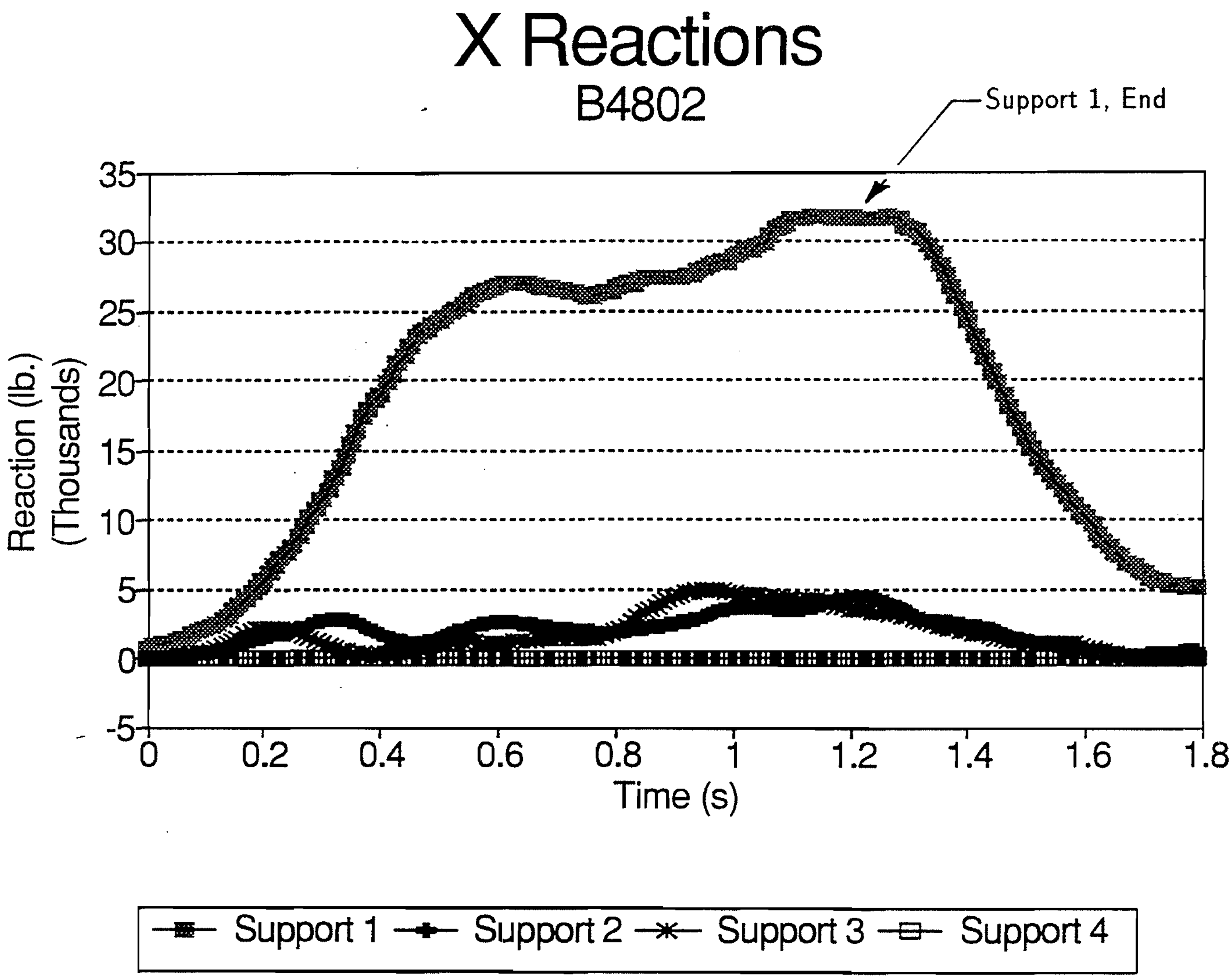
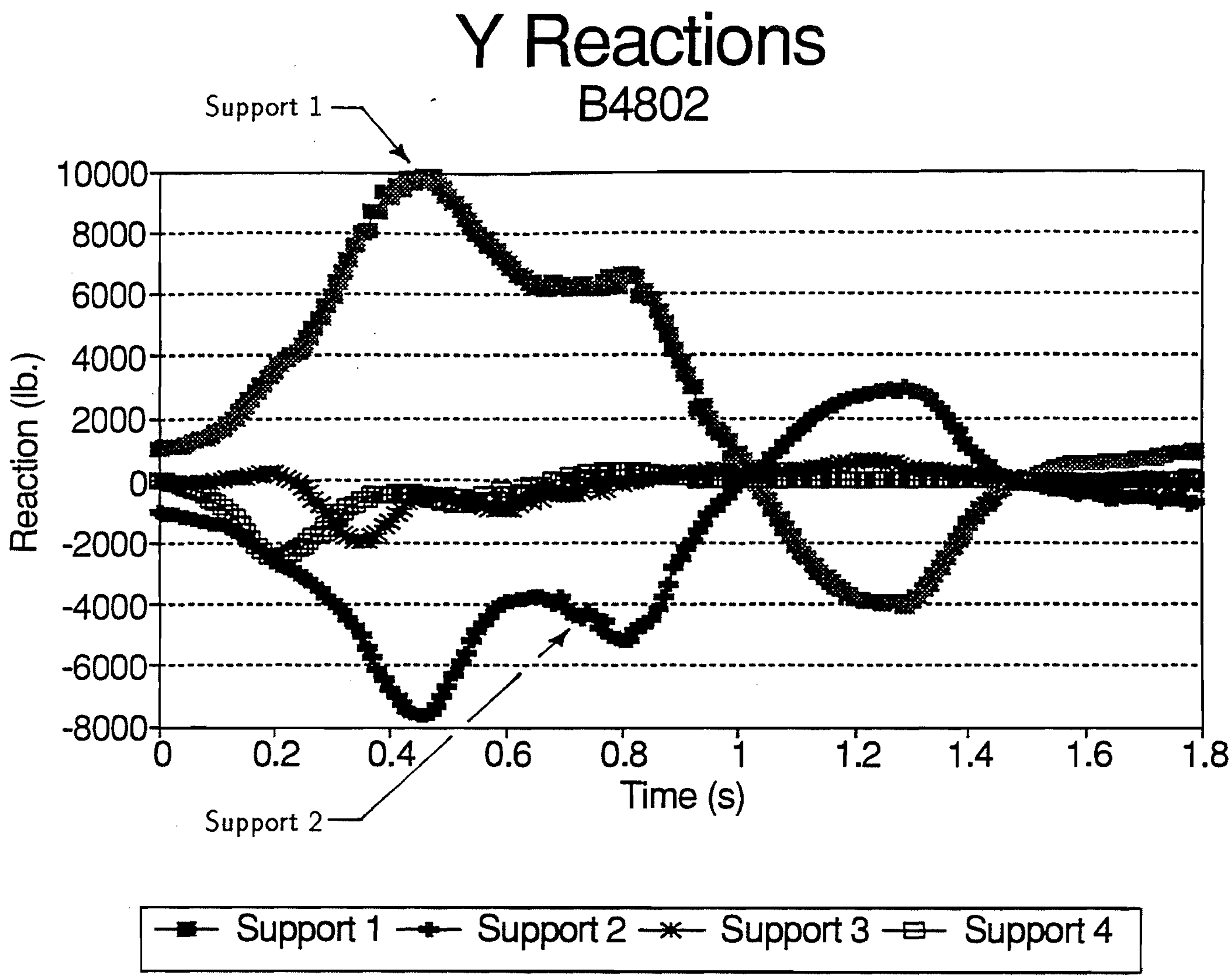


Figure III - 125
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model B



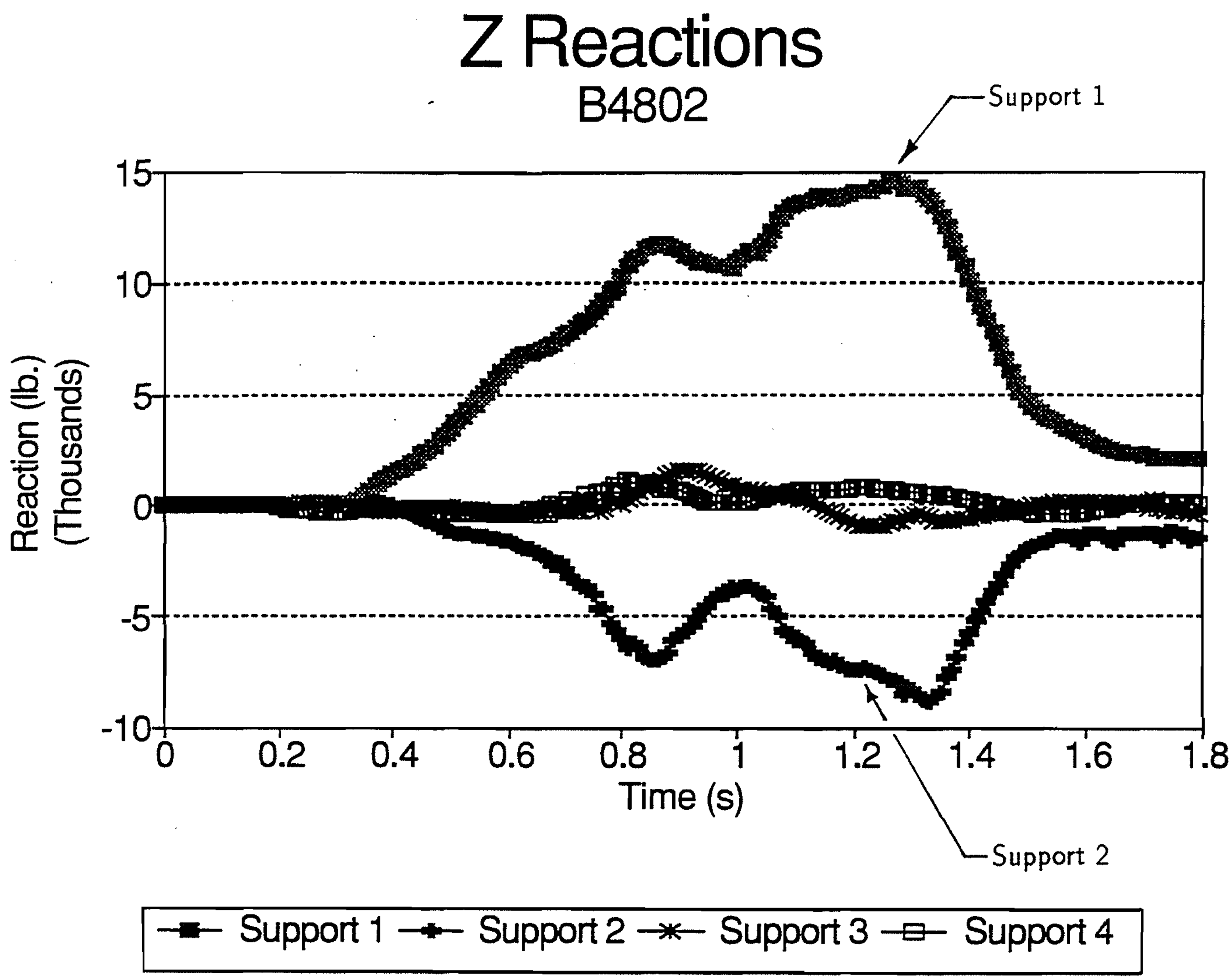
X Reaction, in-plane

Figure III - 126
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model B



Y Reaction, Vertical

Figure III - 127
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model B



Z Reaction, Downslope

Figure III - 128
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model B

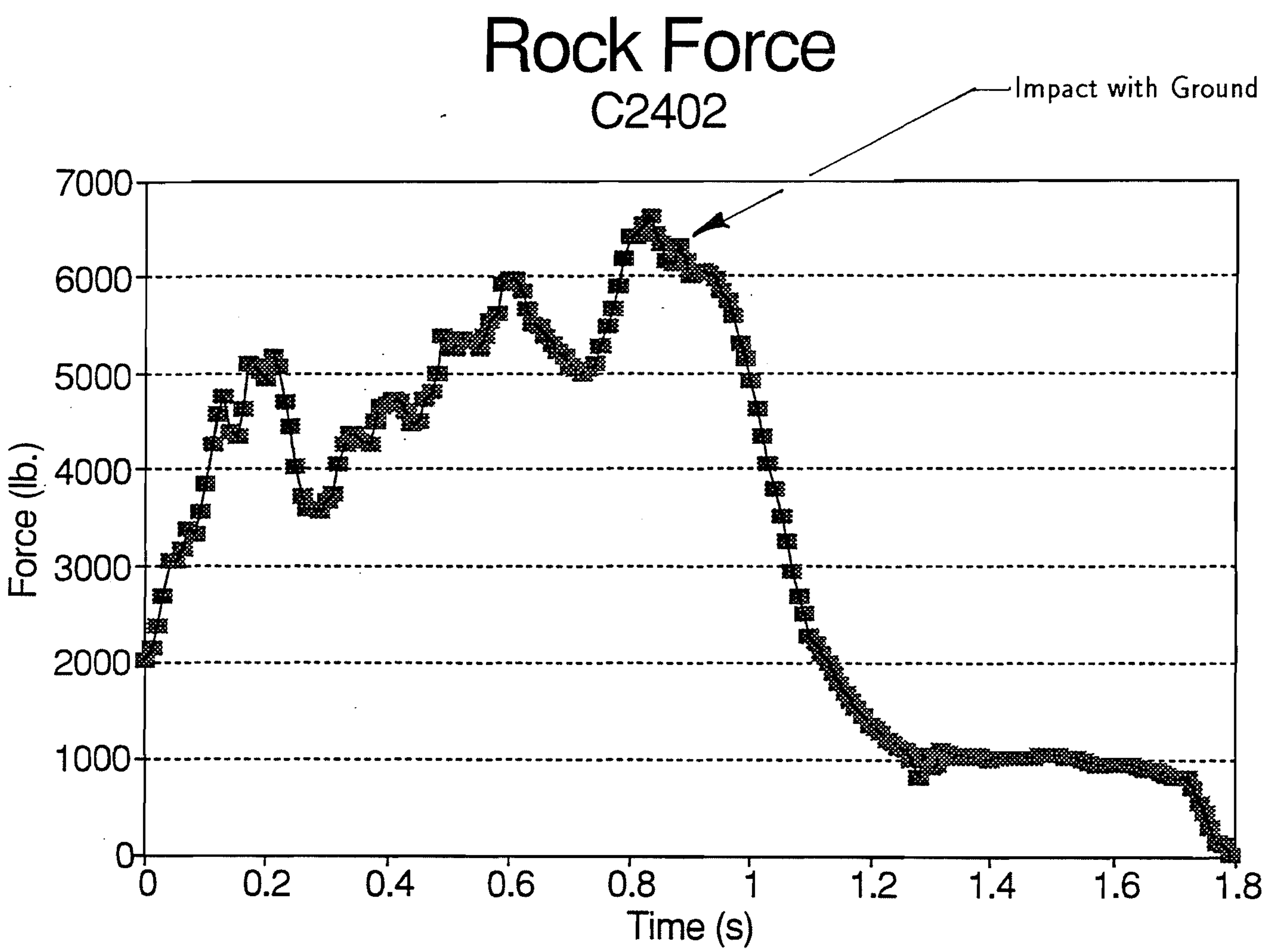


Figure III - 129
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model C

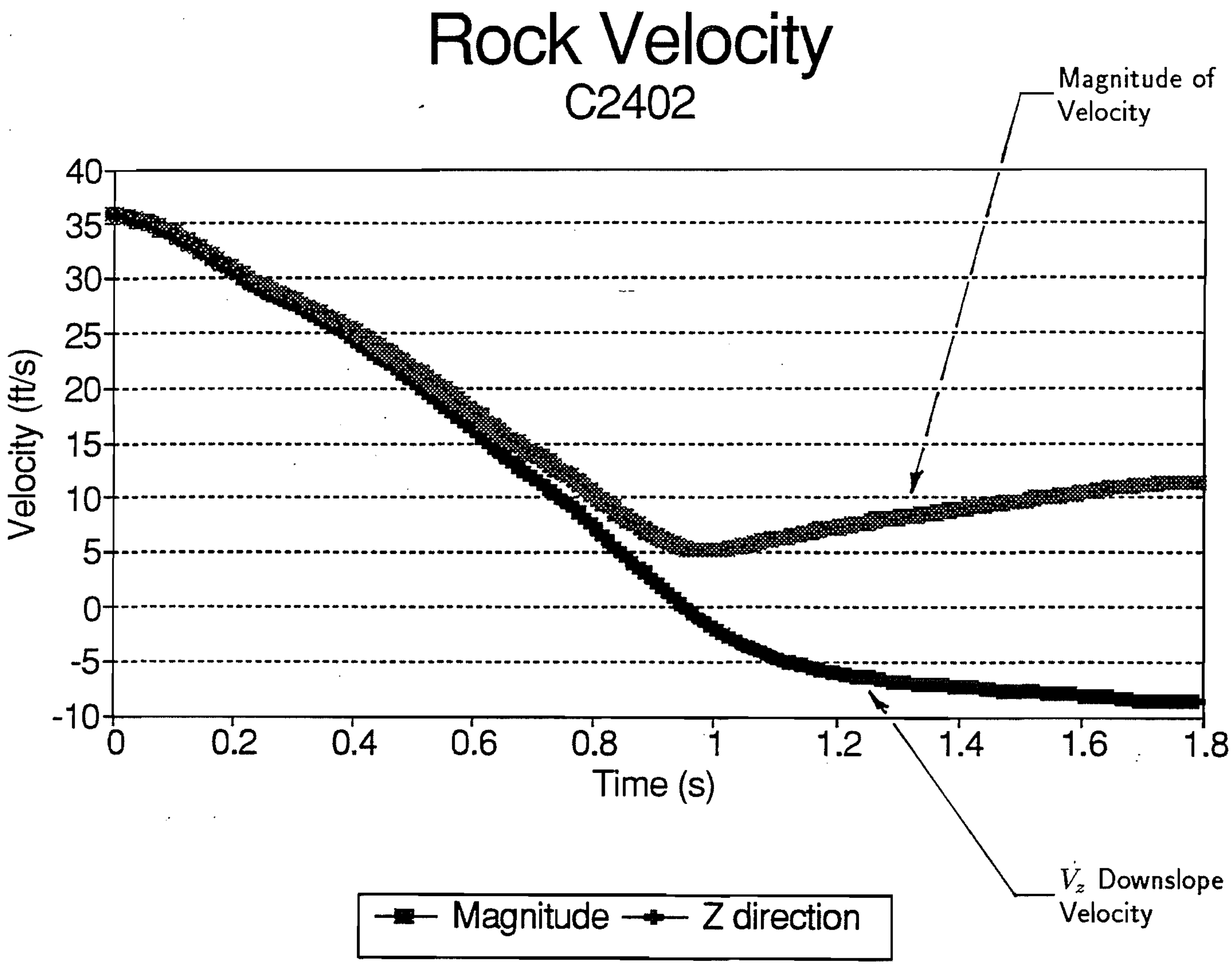


Figure III - 130
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model C

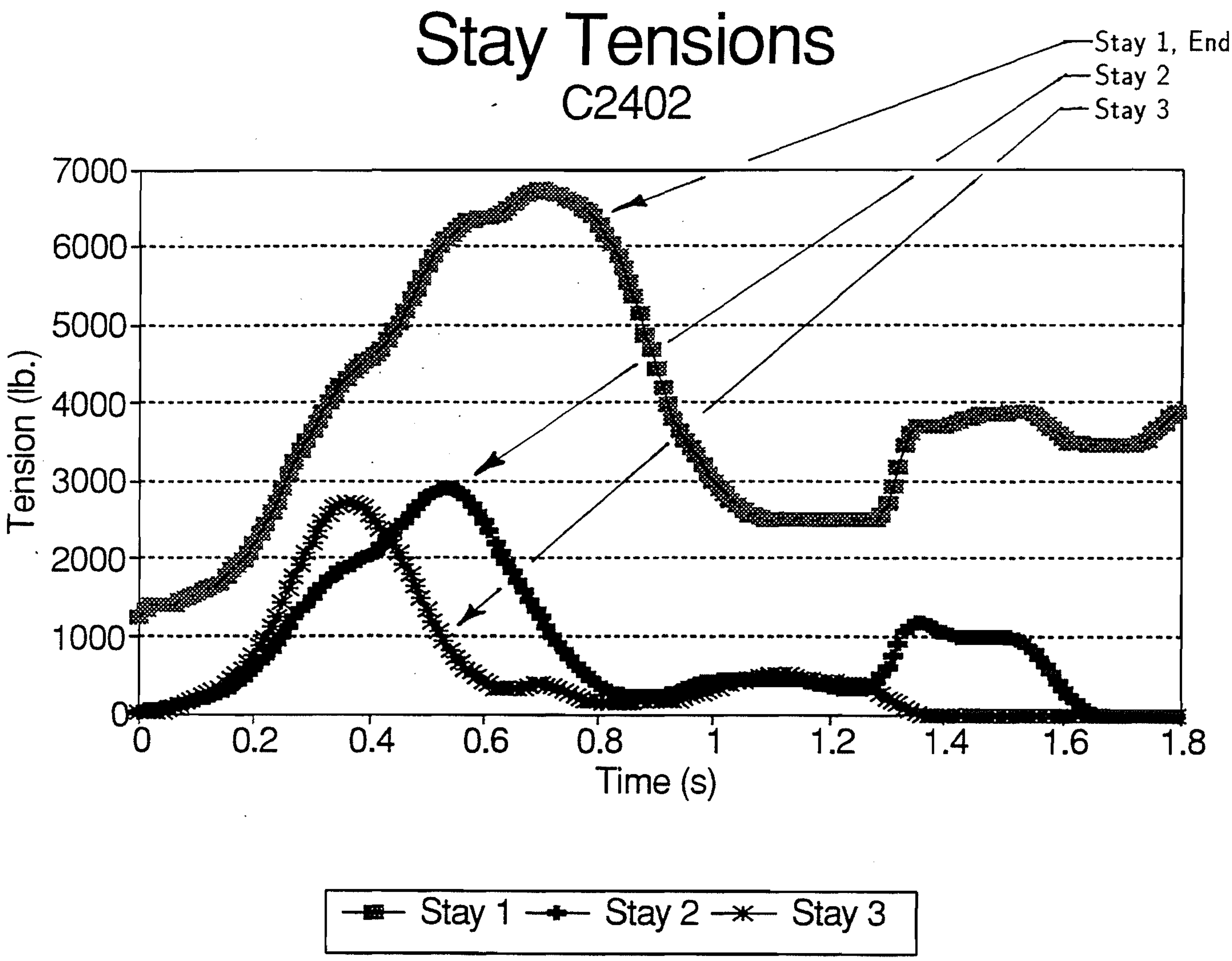


Figure III - 131
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model C

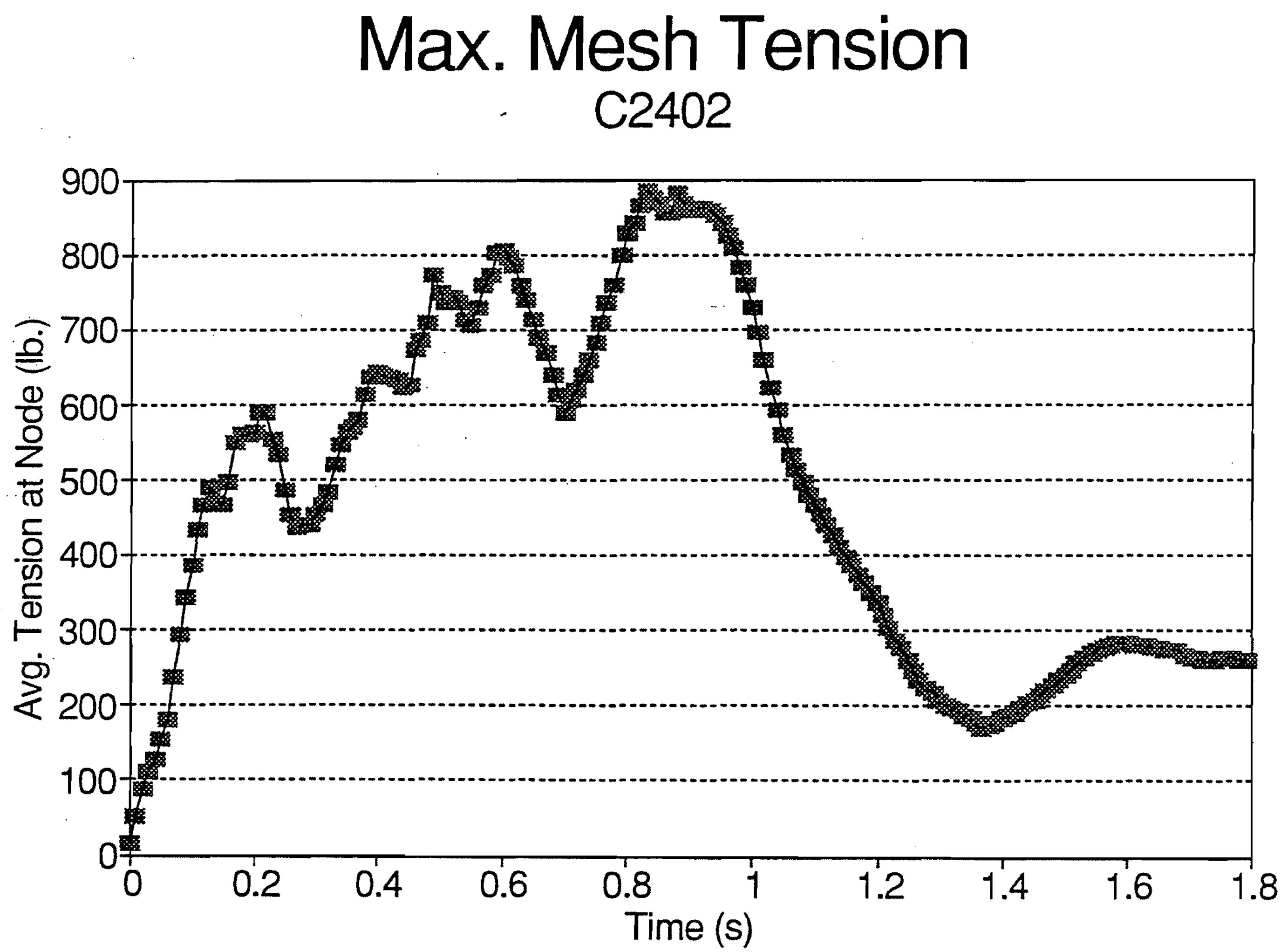


Figure III - 132
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model C

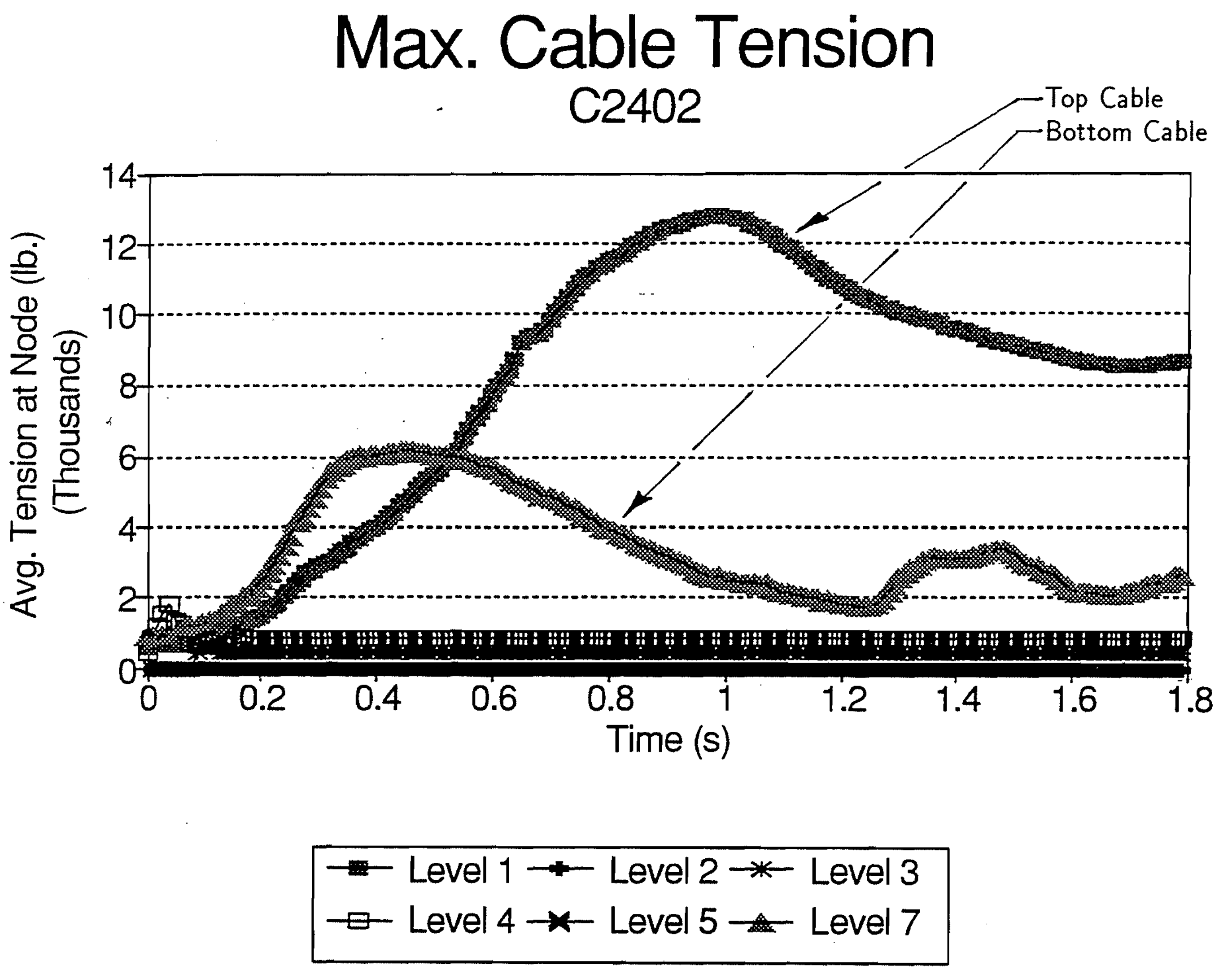
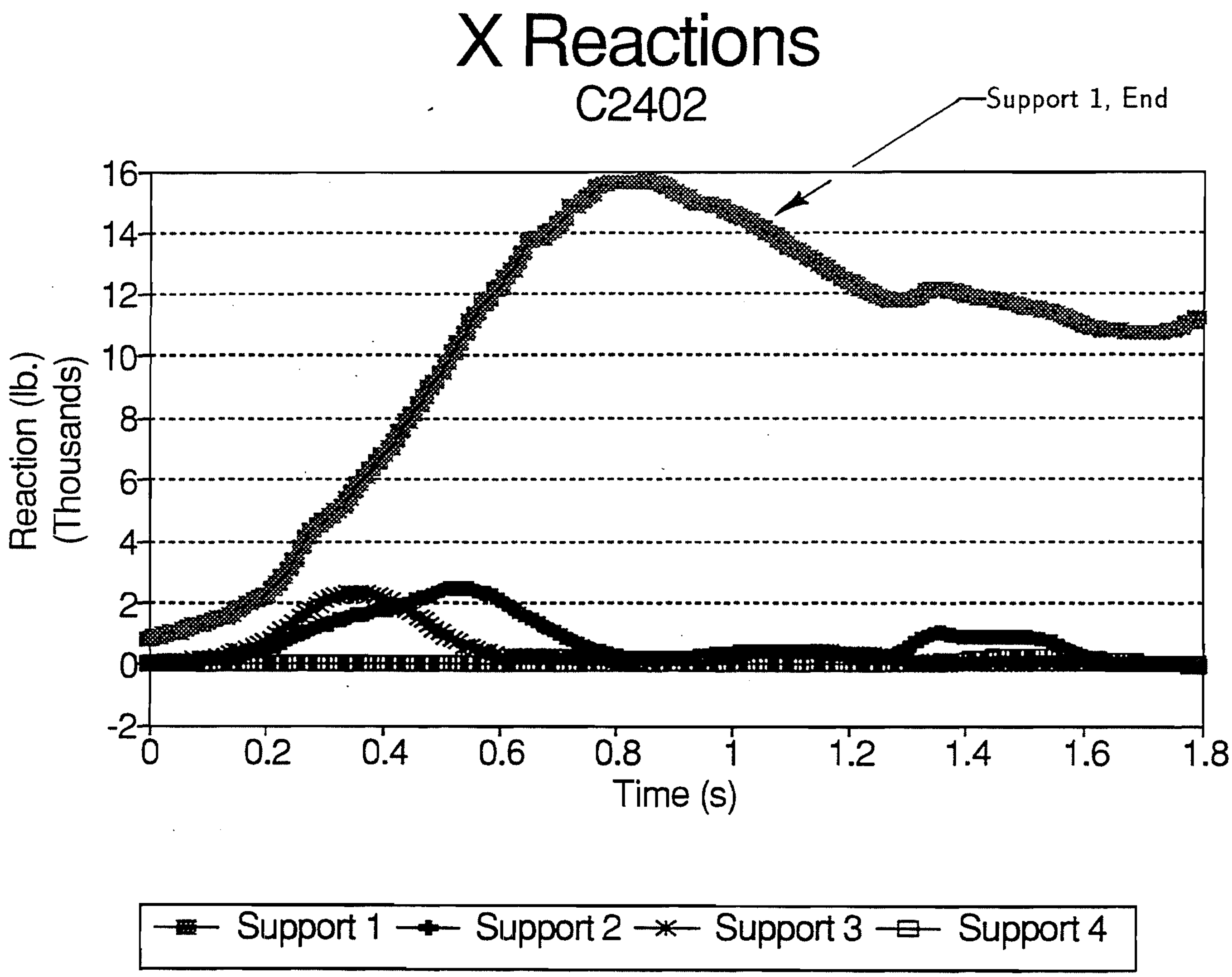
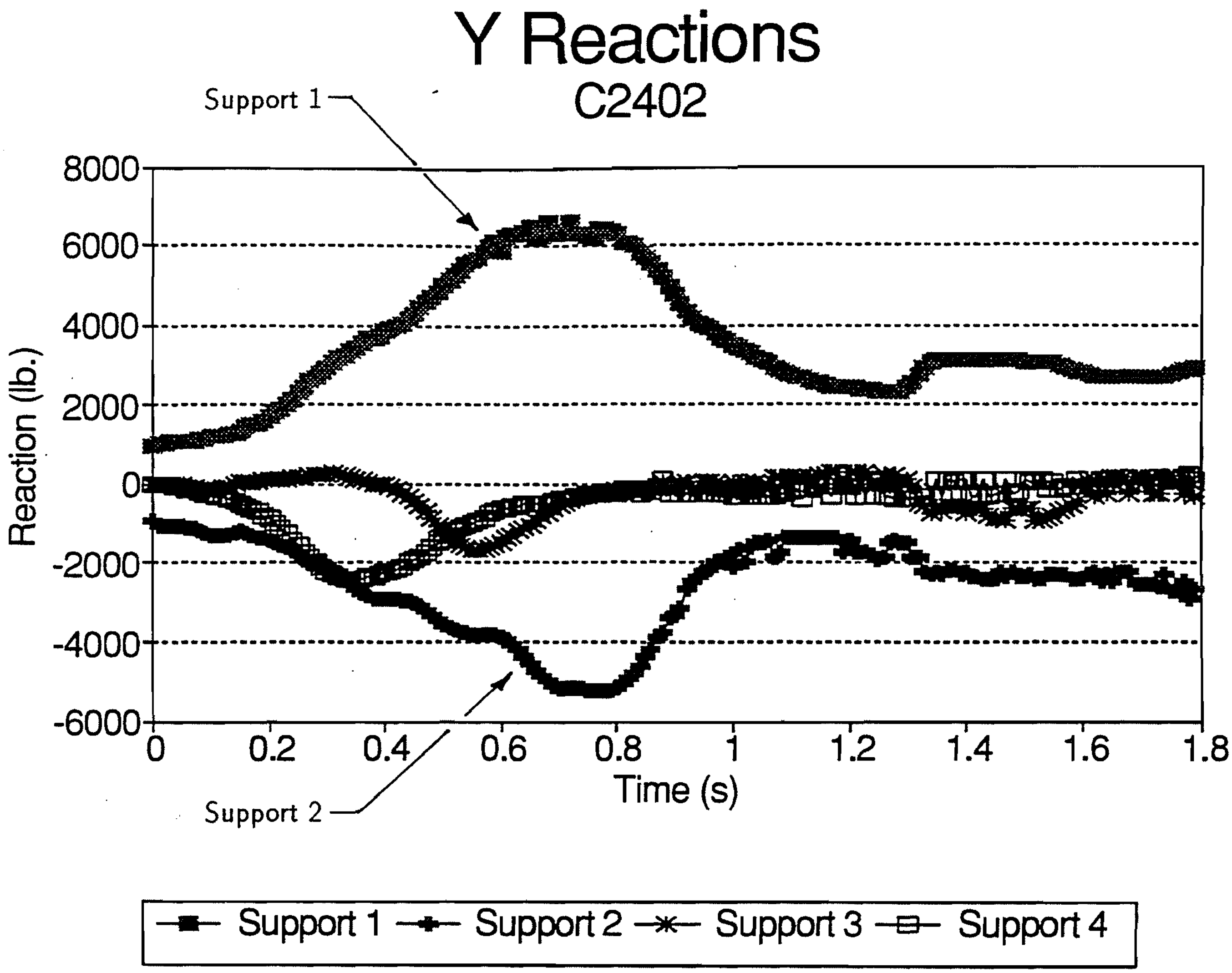


Figure III - 133
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model C



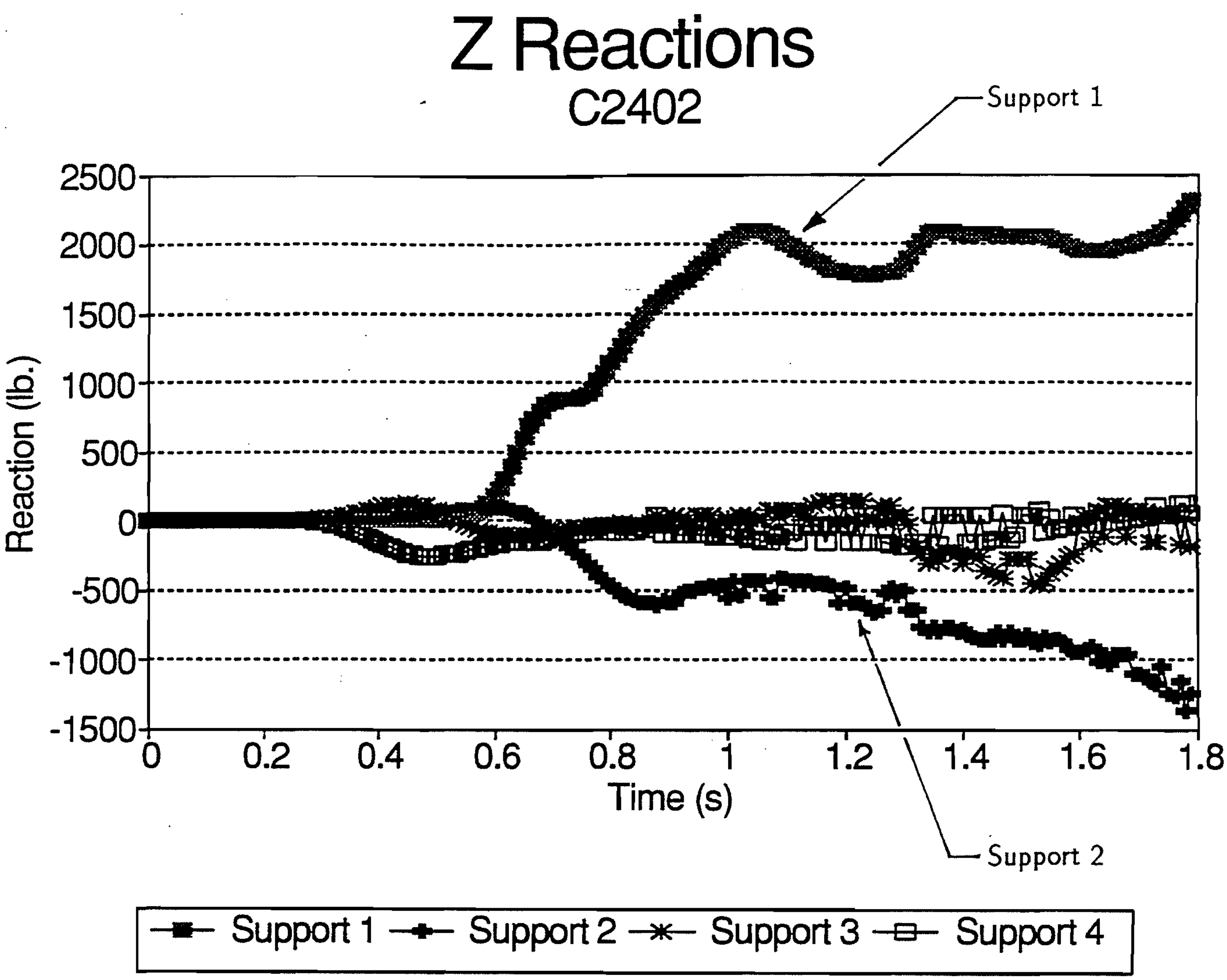
X Reaction, in-plane

Figure III - 134
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model C



Y Reaction, Vertical

Figure III - 135
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model C



Z Reaction, Downslope

Figure III - 136
Rockfall: 2,000 lbs. 40,000 ft-lbs
Model C

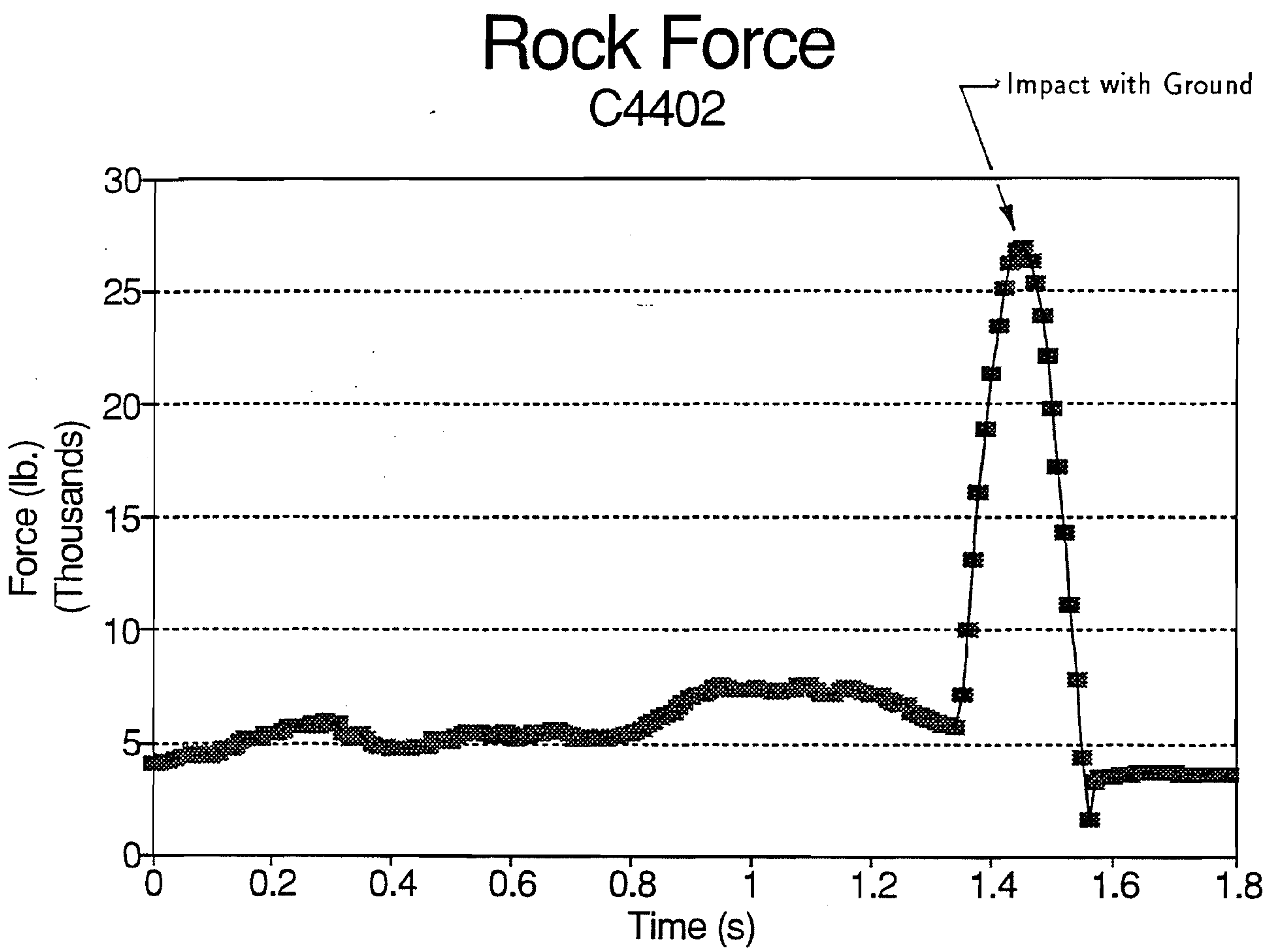


Figure III - 137
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model C

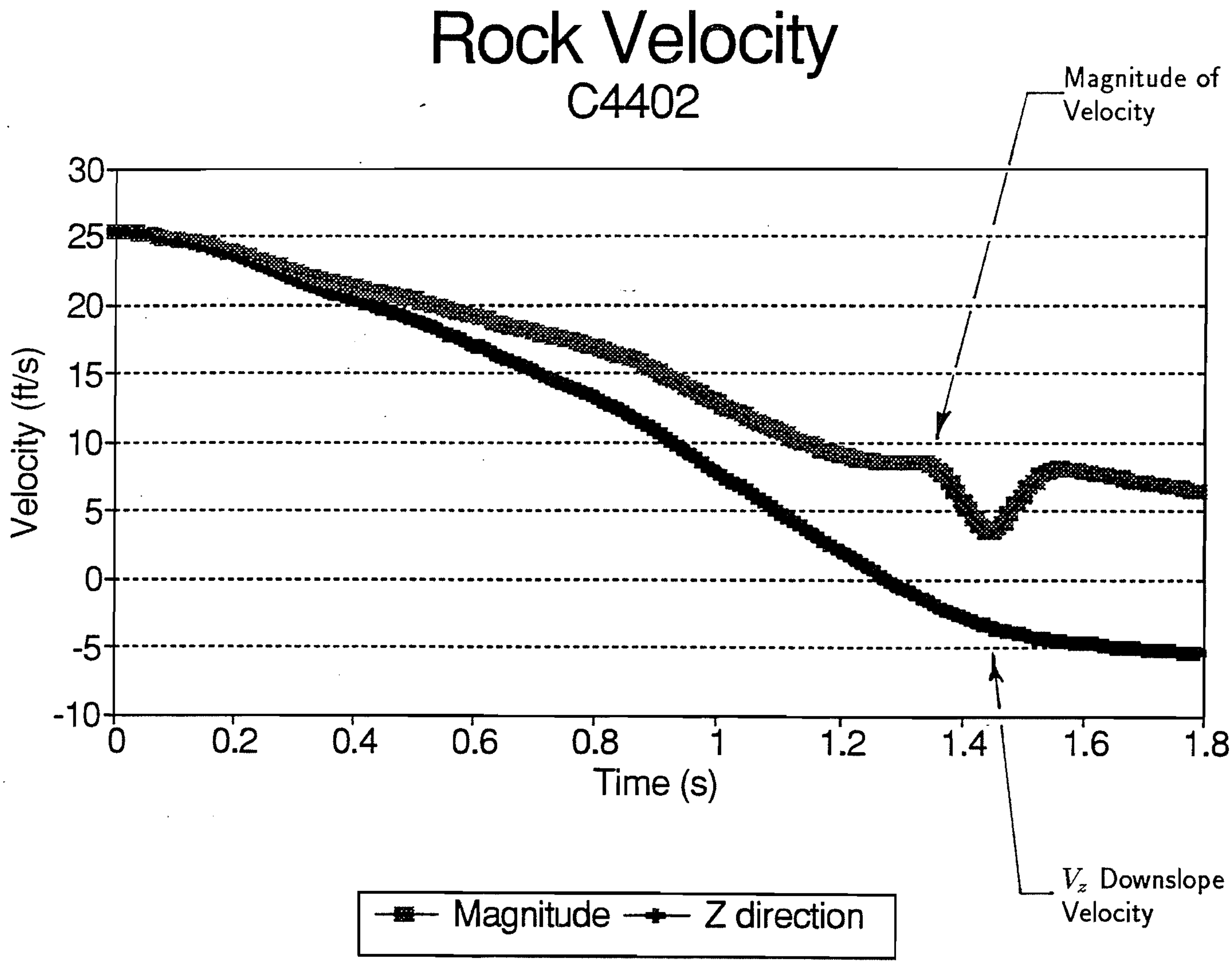


Figure III - 138
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model C

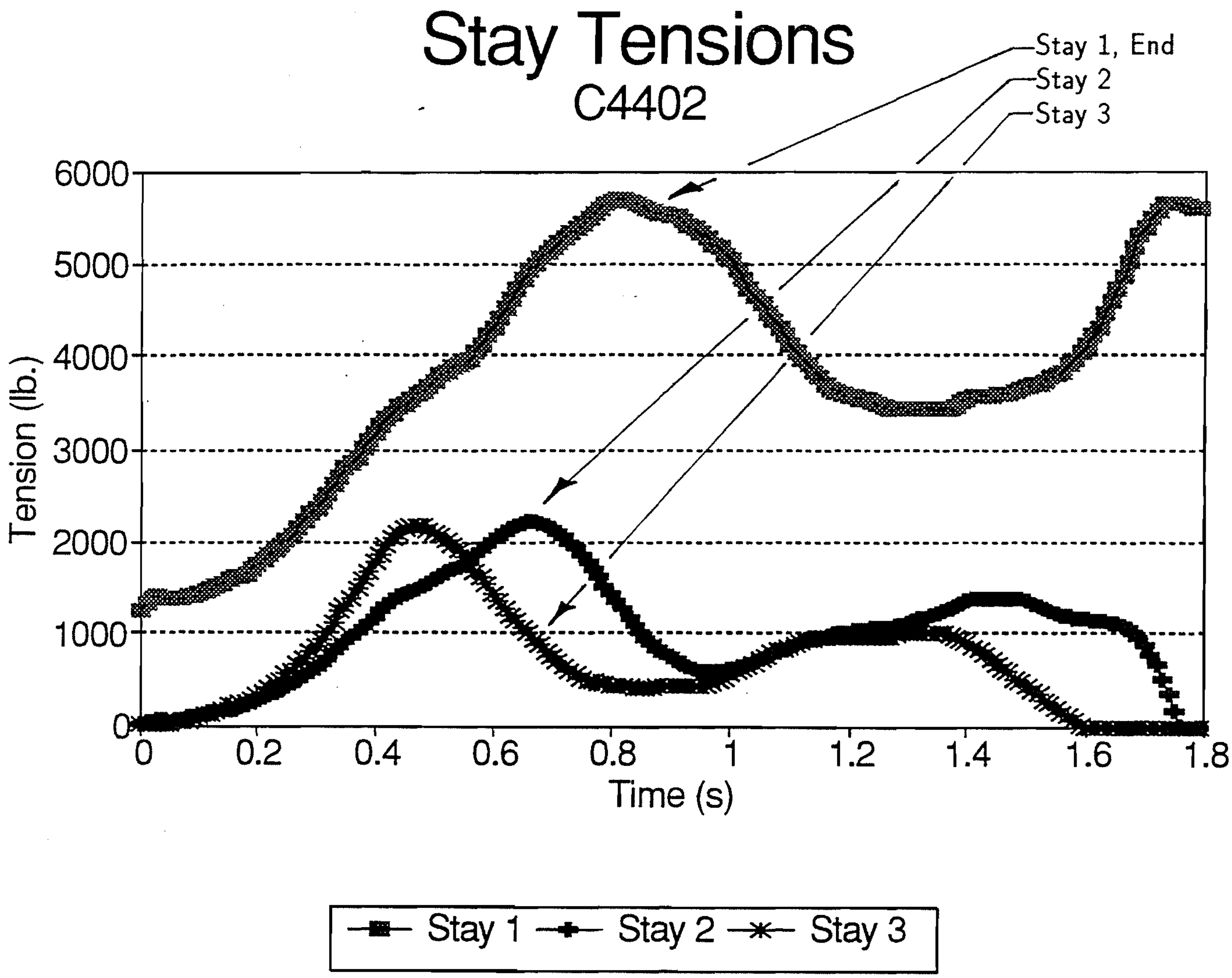


Figure III - 139
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model C

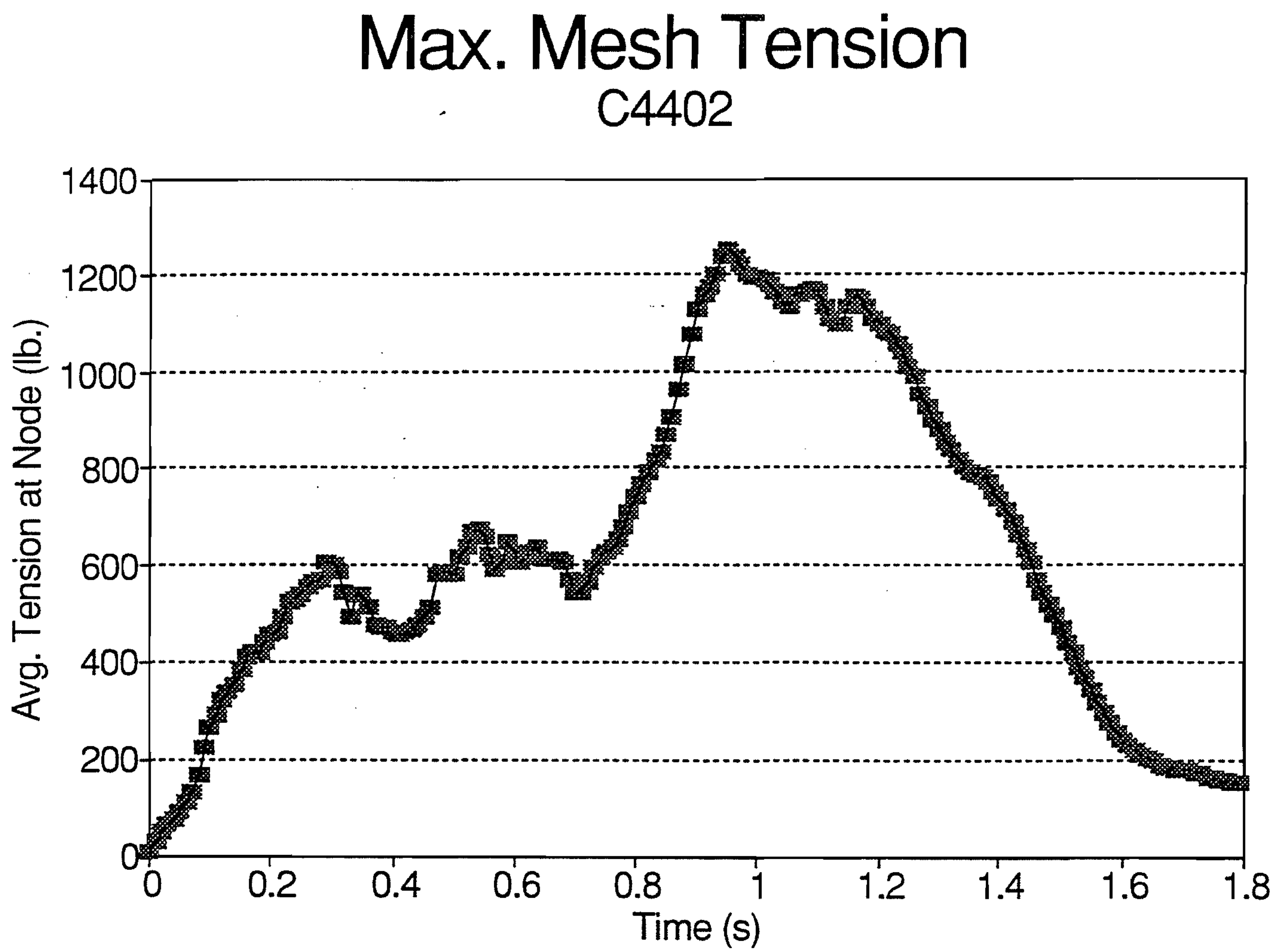


Figure III - 140
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model C

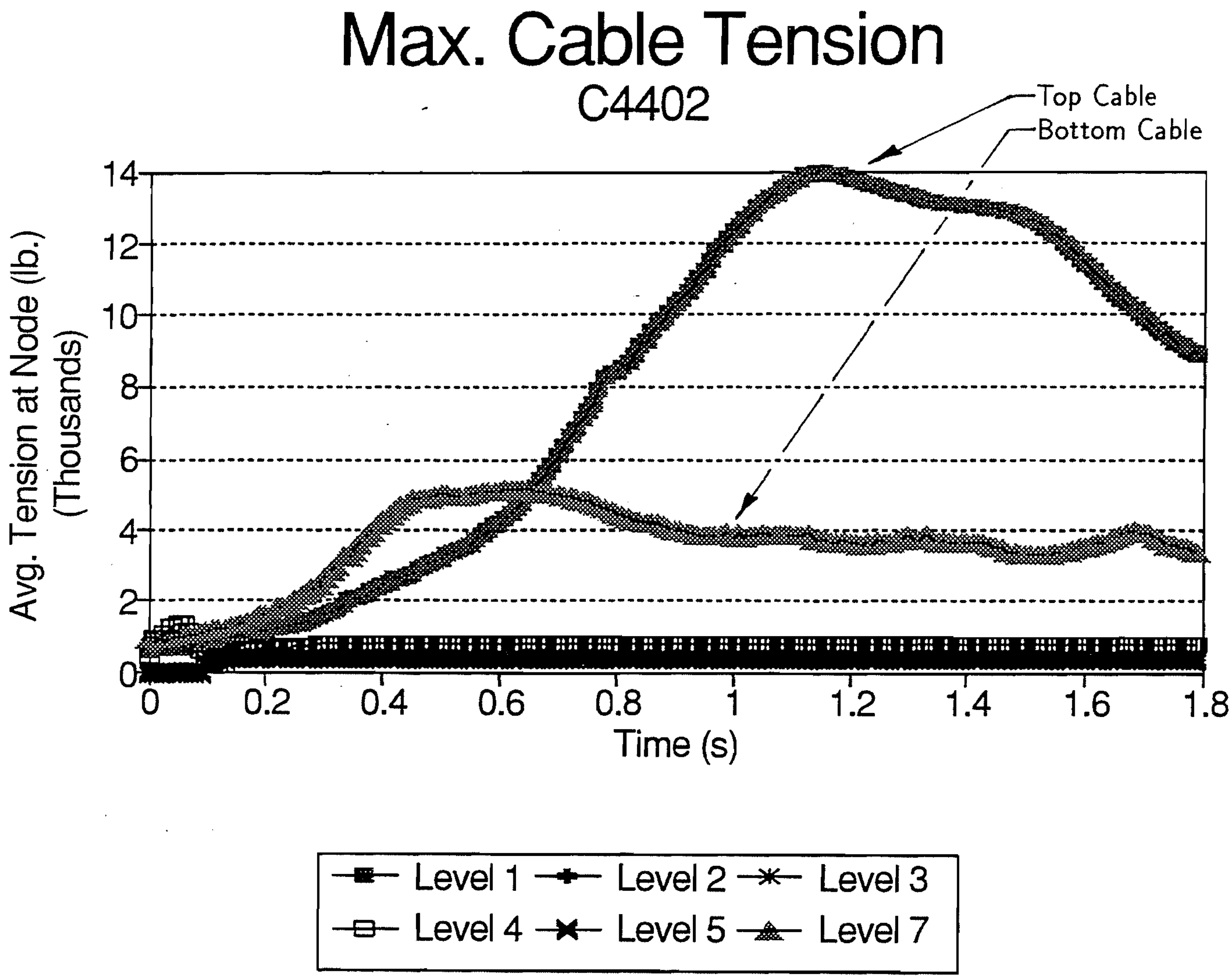
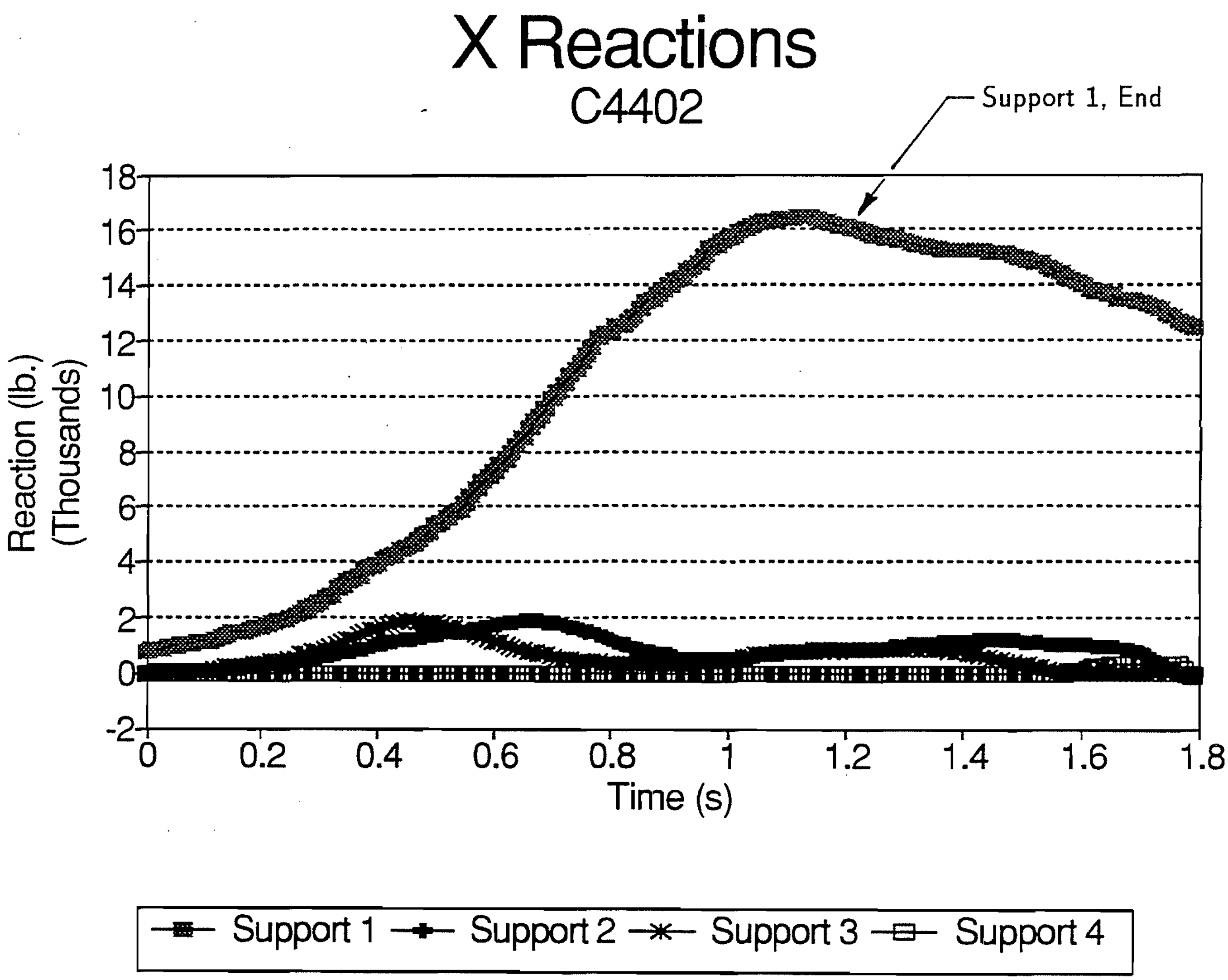
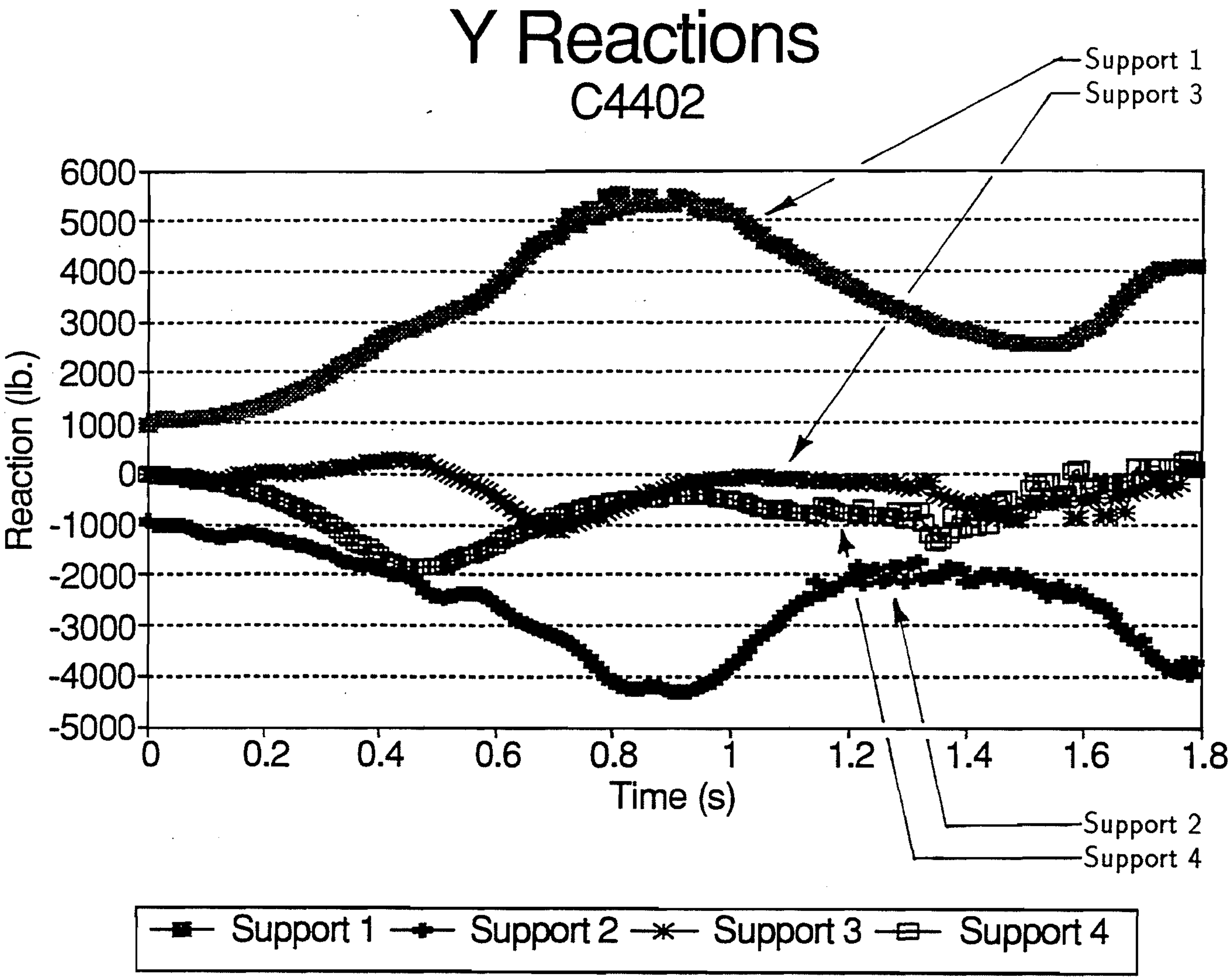


Figure III - 141
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model C



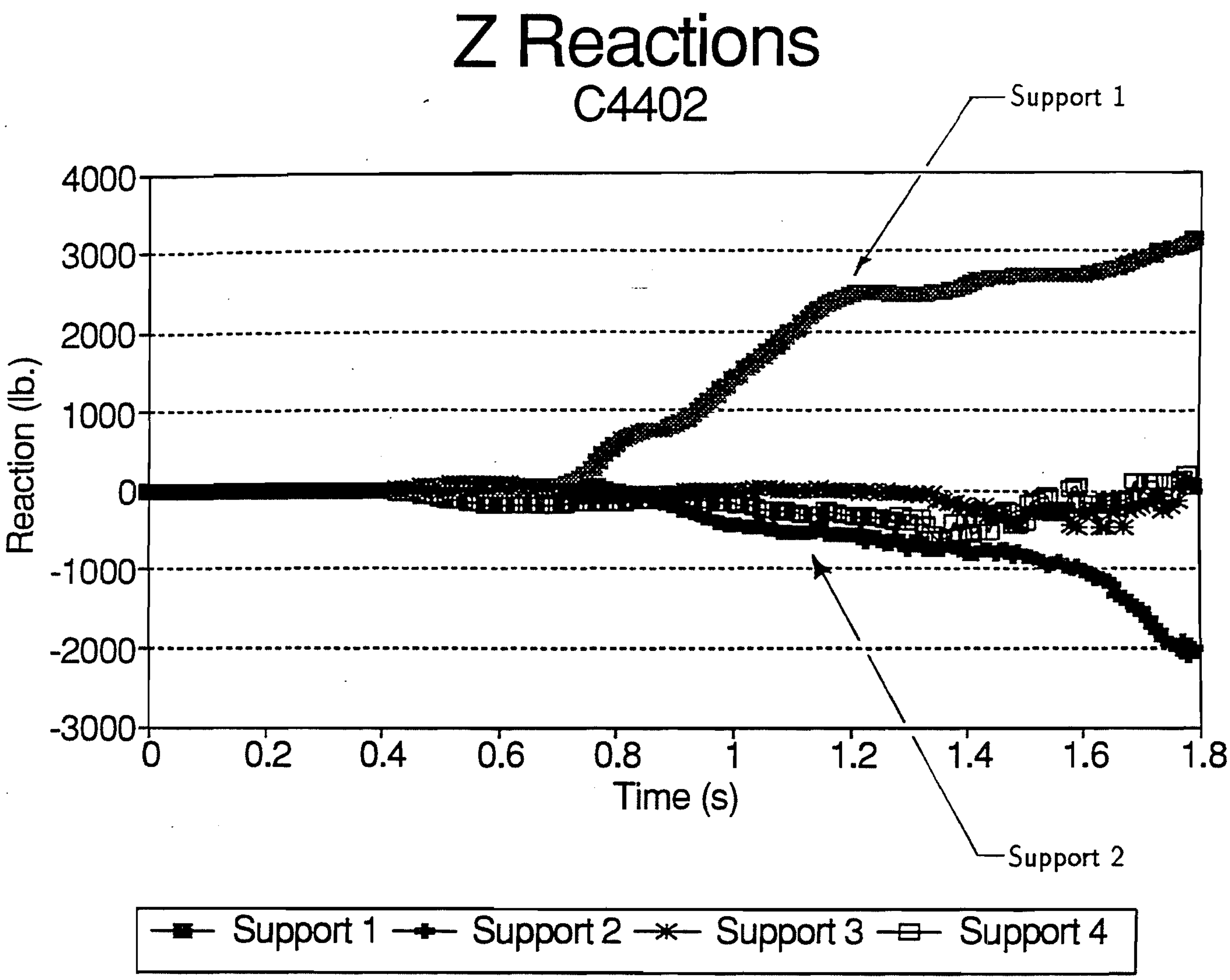
X Reaction, in-plane

Figure III - 142
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model C



Y Reaction, Vertical

Figure III - 143
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model C



Z Reaction, Downslope

Figure III - 144
Rockfall: 4,000 lbs. 40,000 ft-lbs
Model C

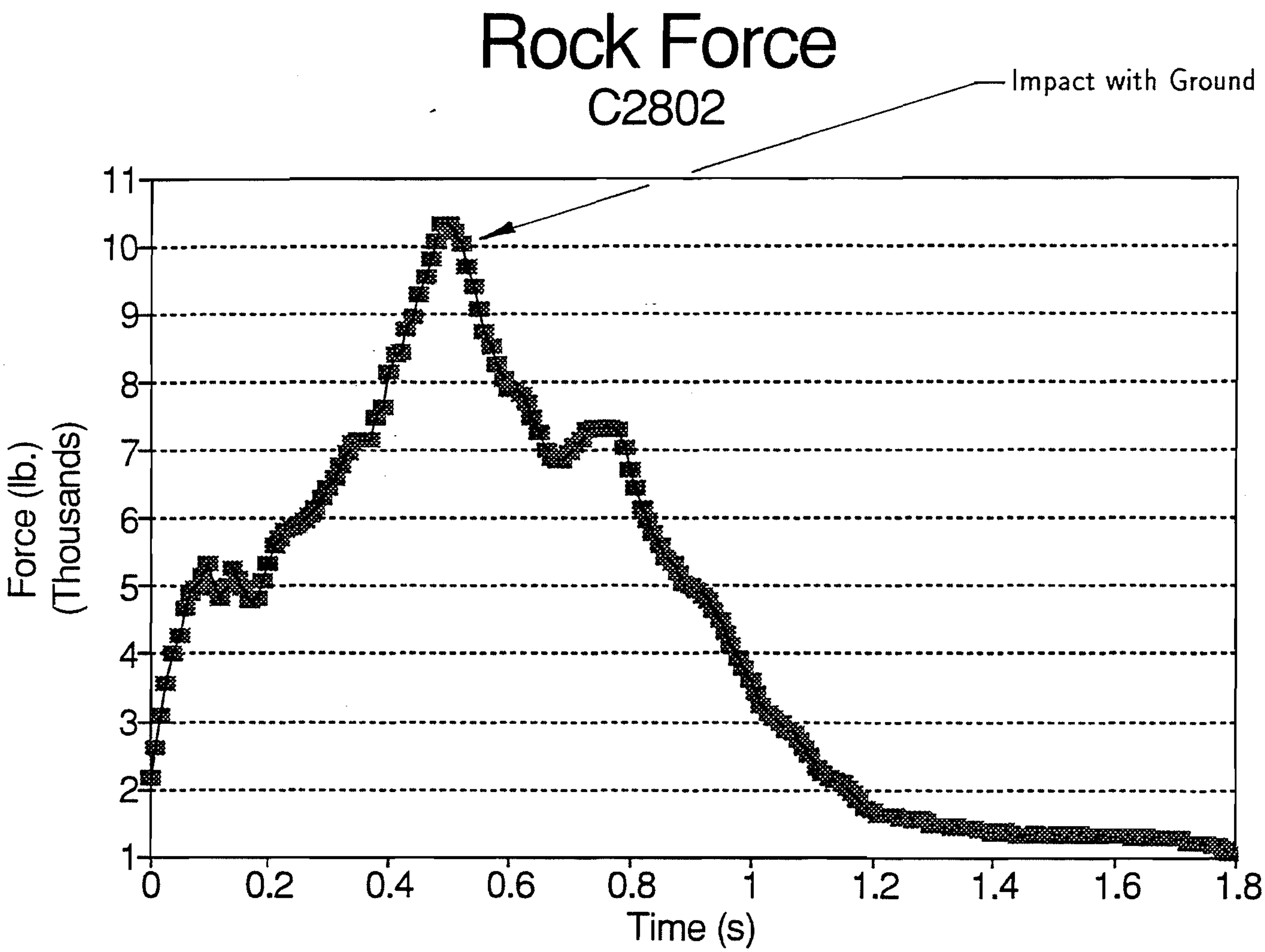


Figure III - 145
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model C

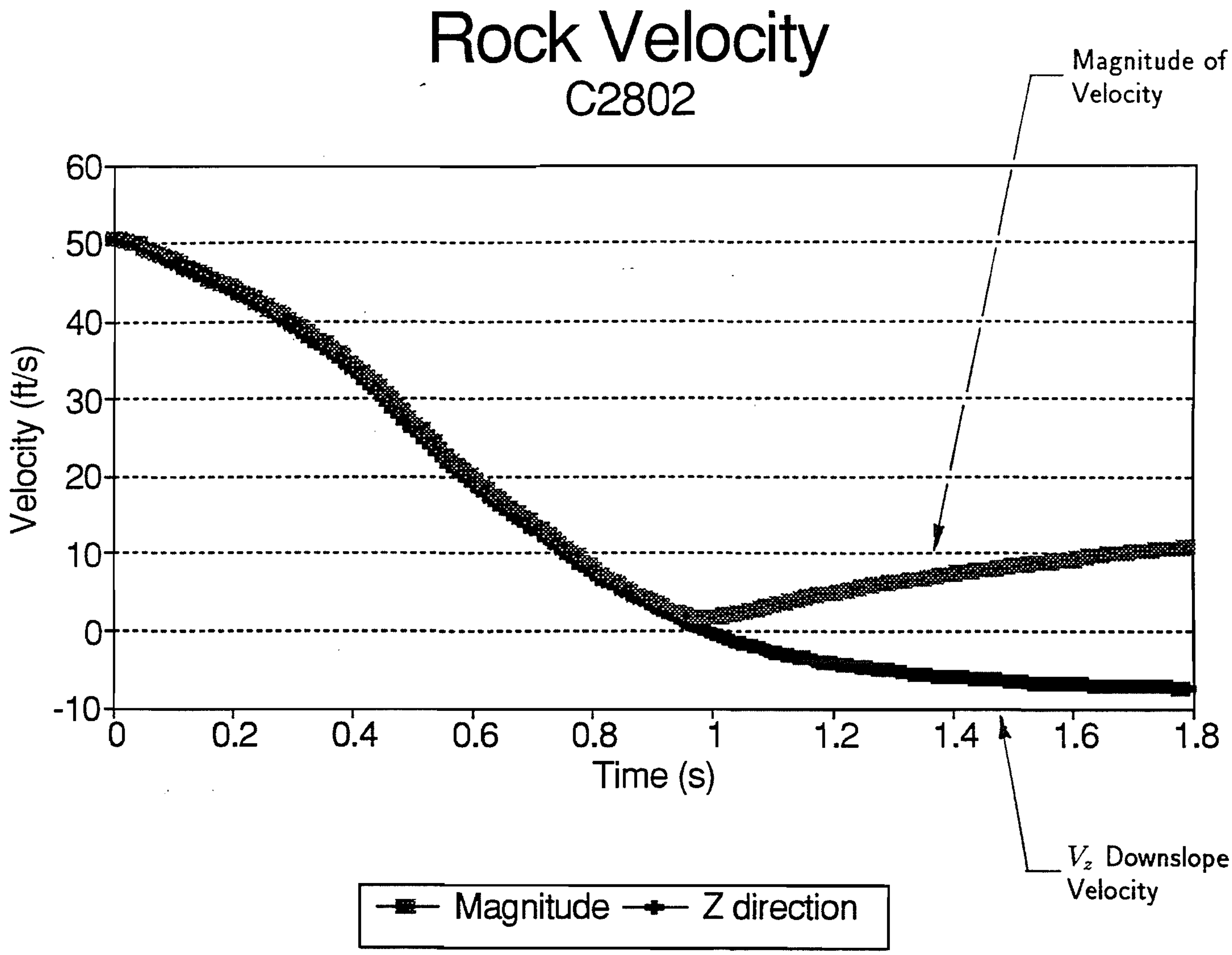


Figure III - 146
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model C

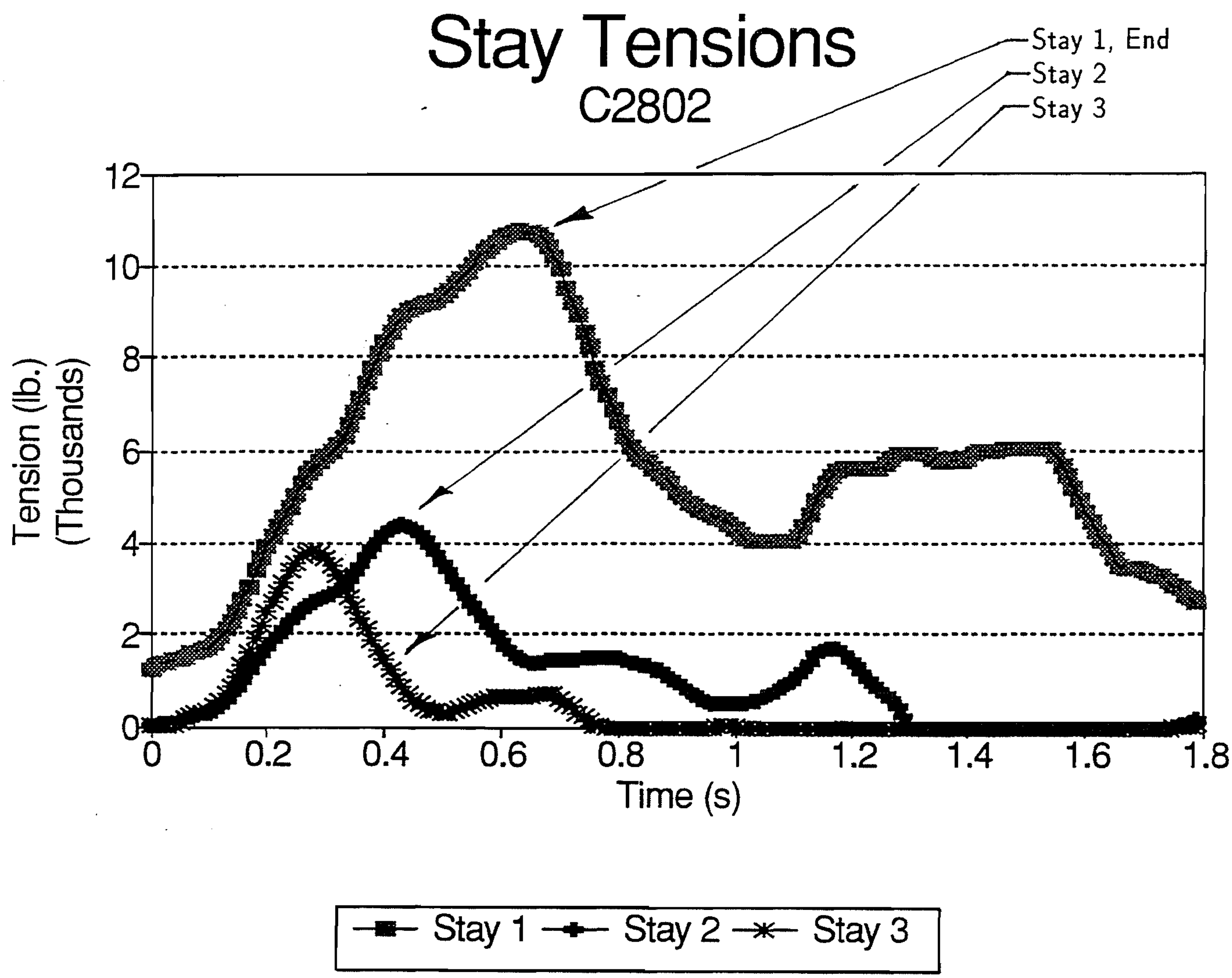


Figure III - 147
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model C

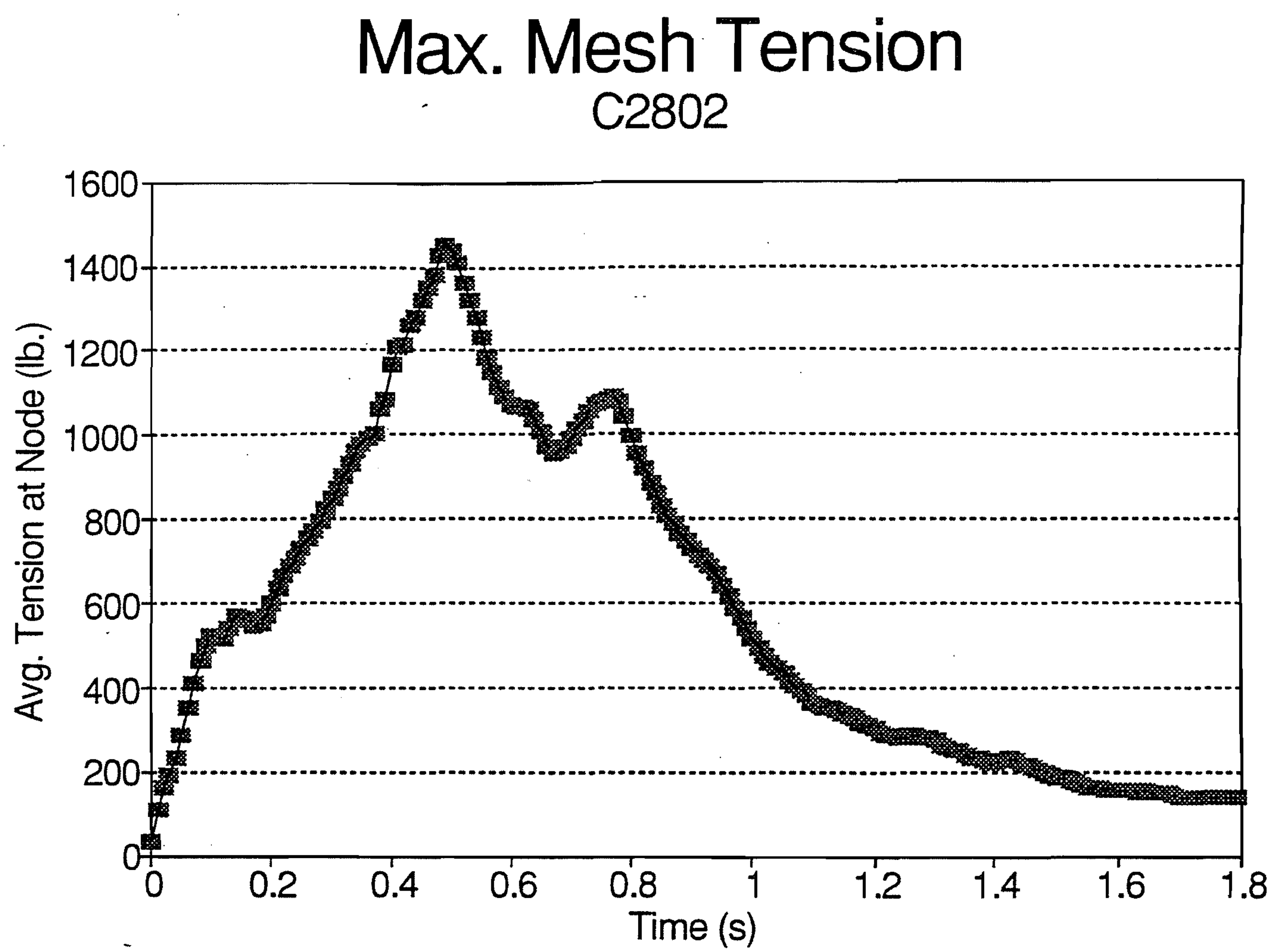


Figure III - 148
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model C

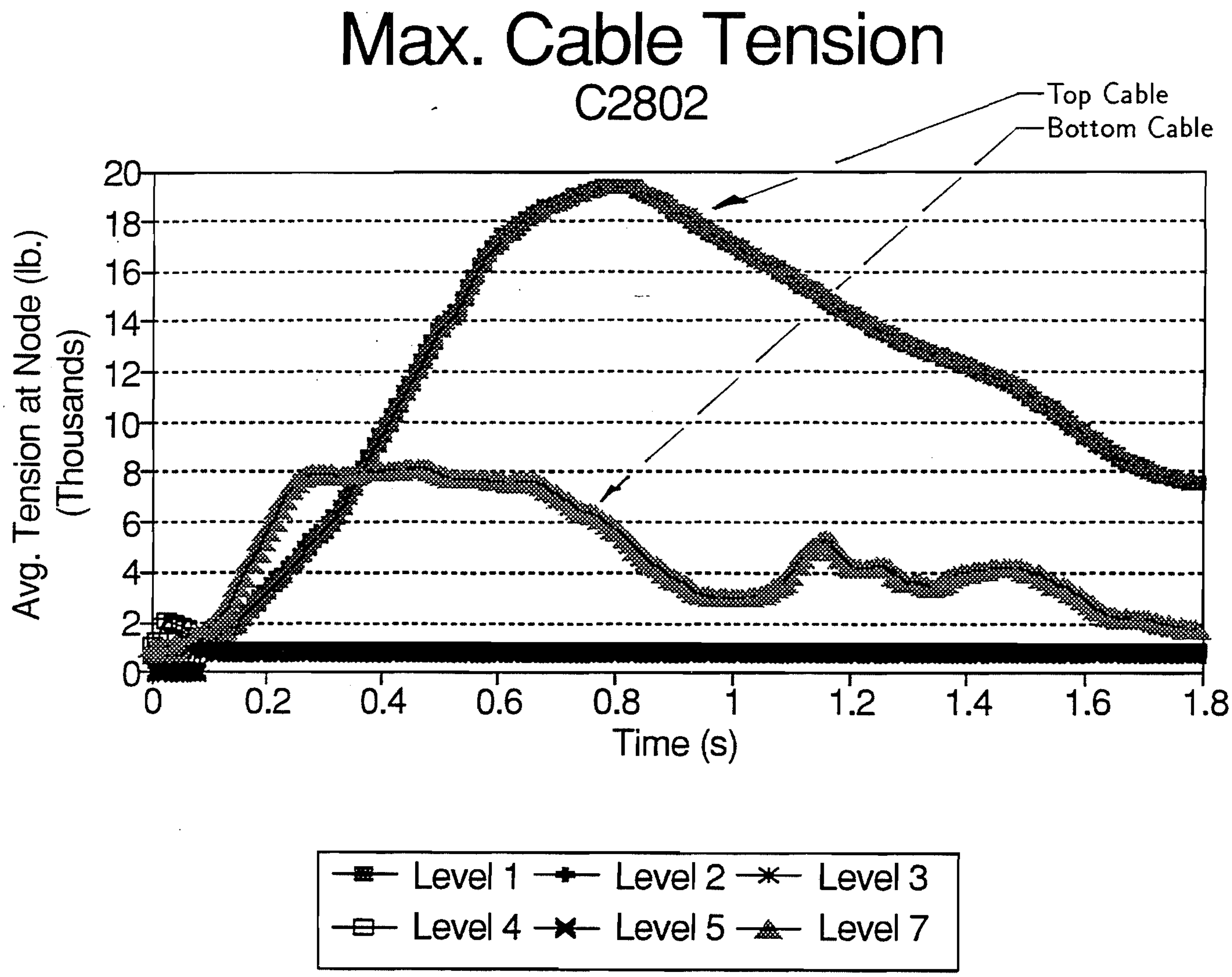
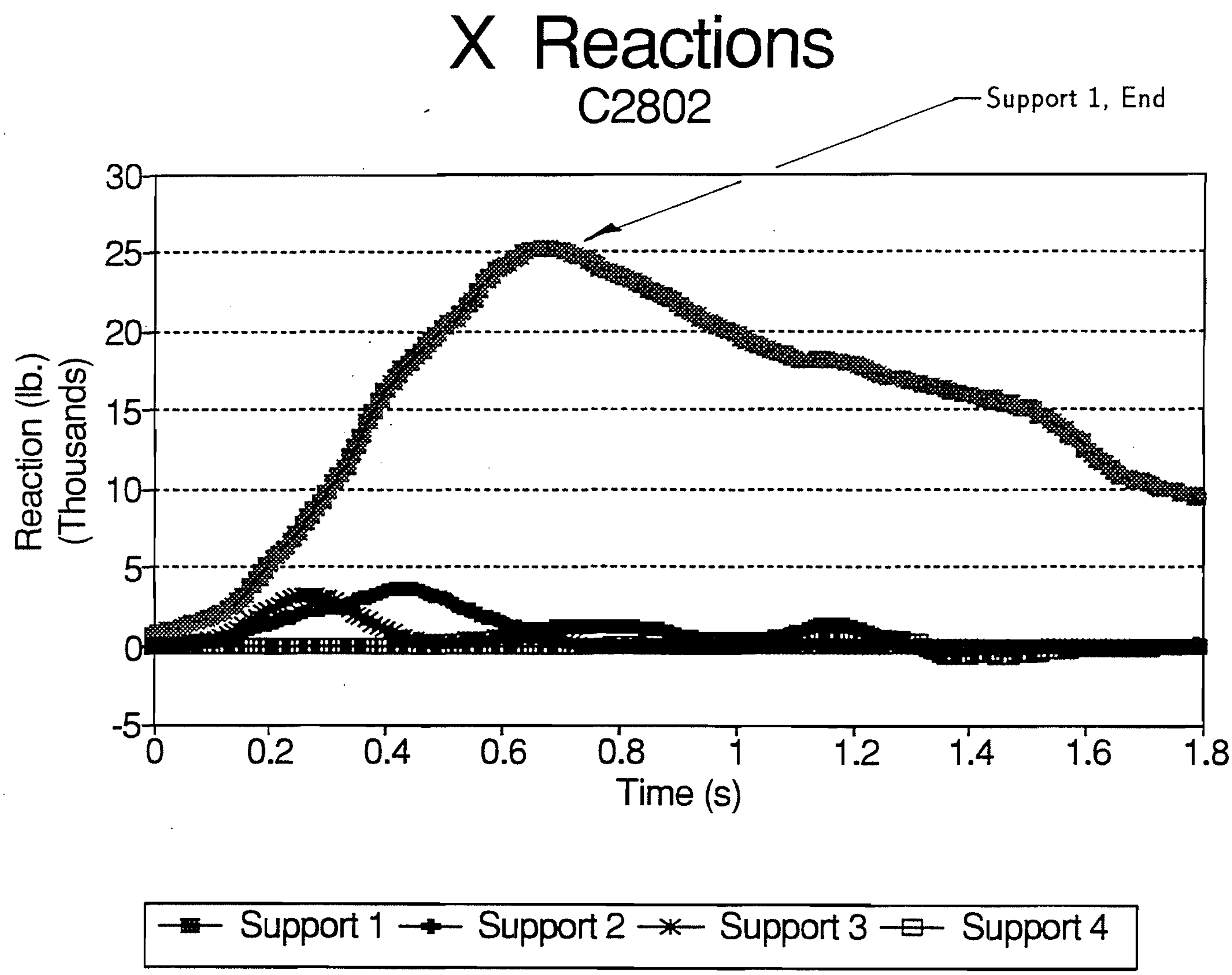
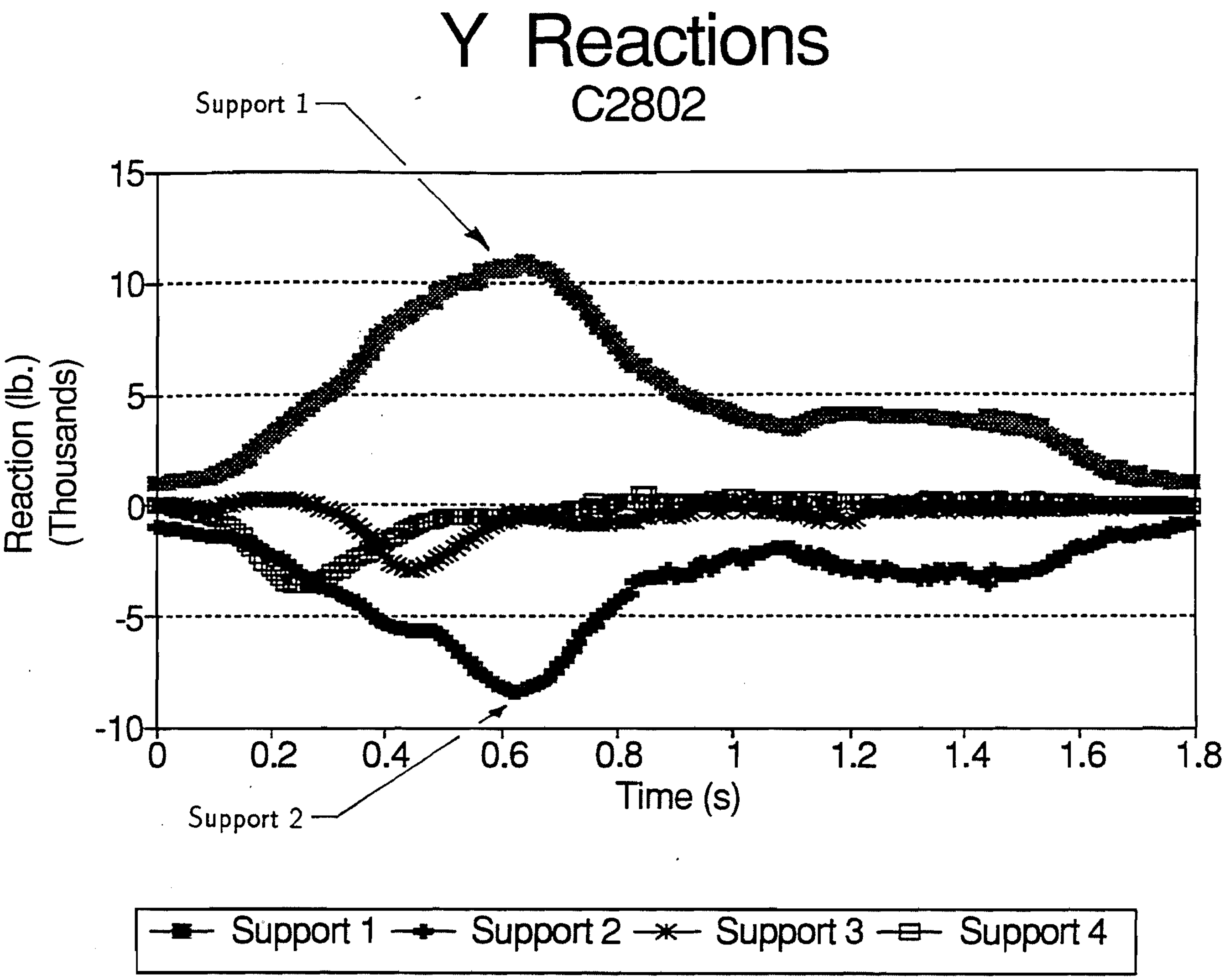


Figure III - 149
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model C



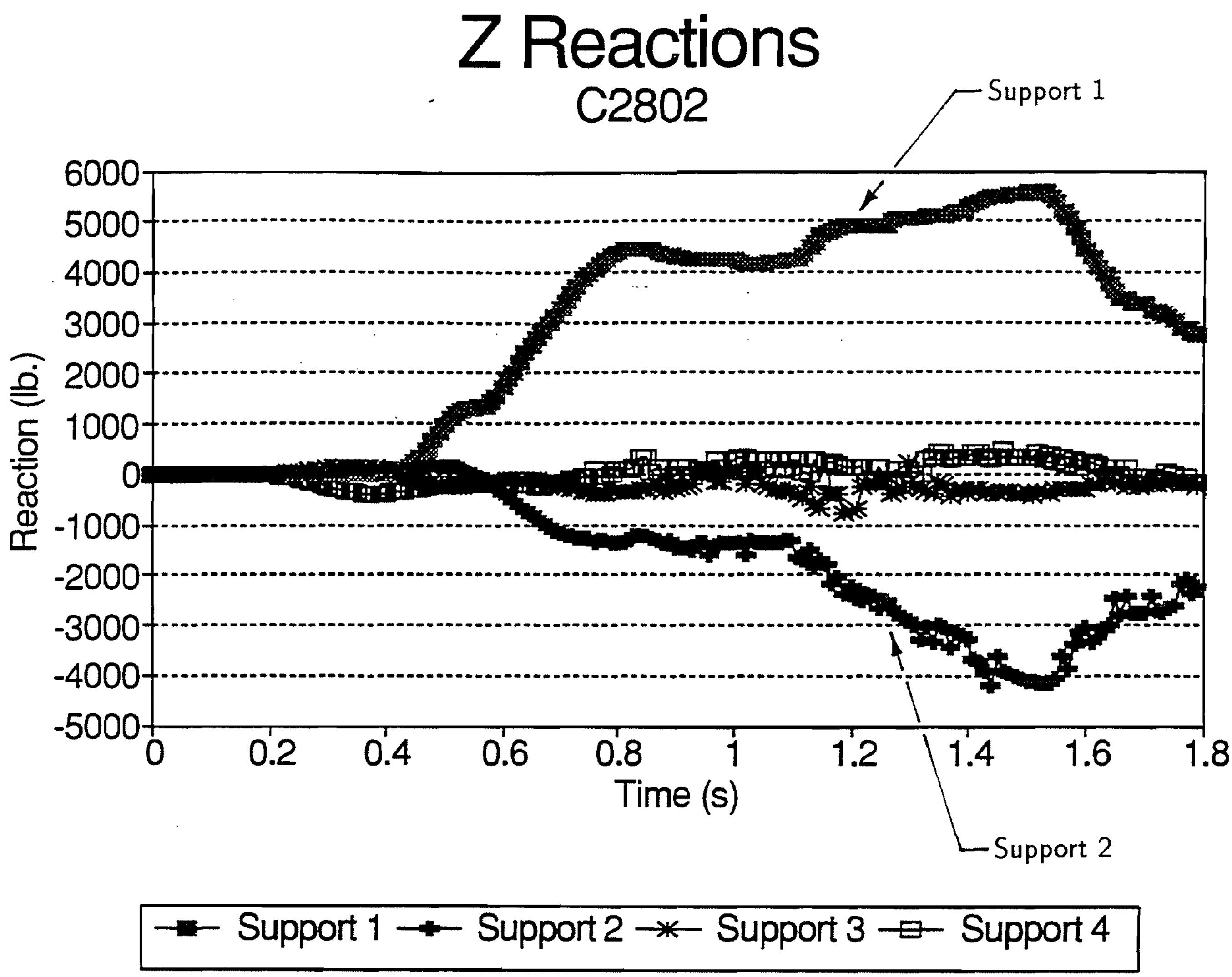
X Reaction, in-plane

Figure III - 150
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model C



Y Reaction, Vertical

Figure III - 151
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model C



Z Reaction, Downslope

Figure III - 152
Rockfall: 2,000 lbs. 80,000 ft-lbs
Model C

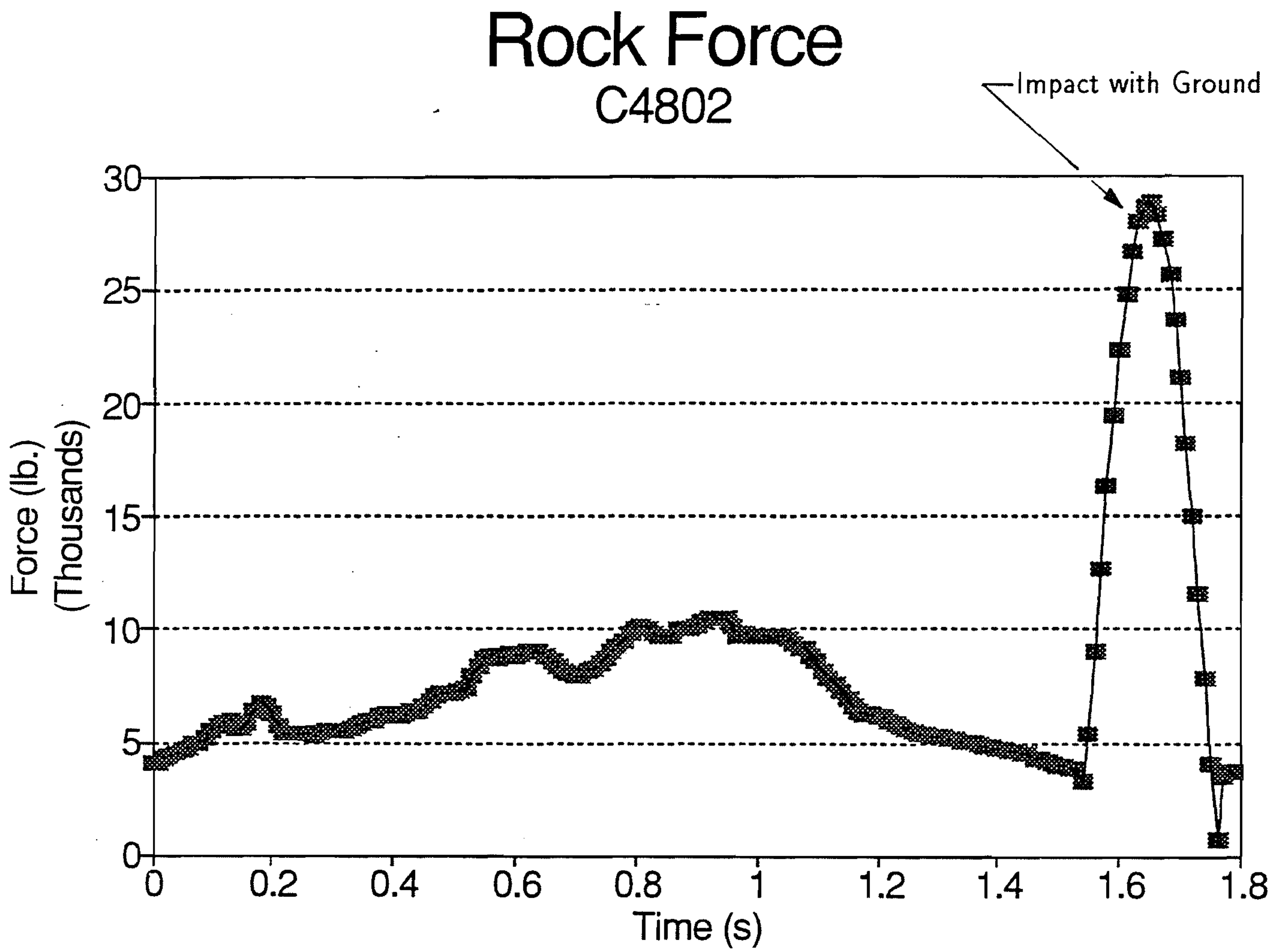


Figure III - 153
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model C

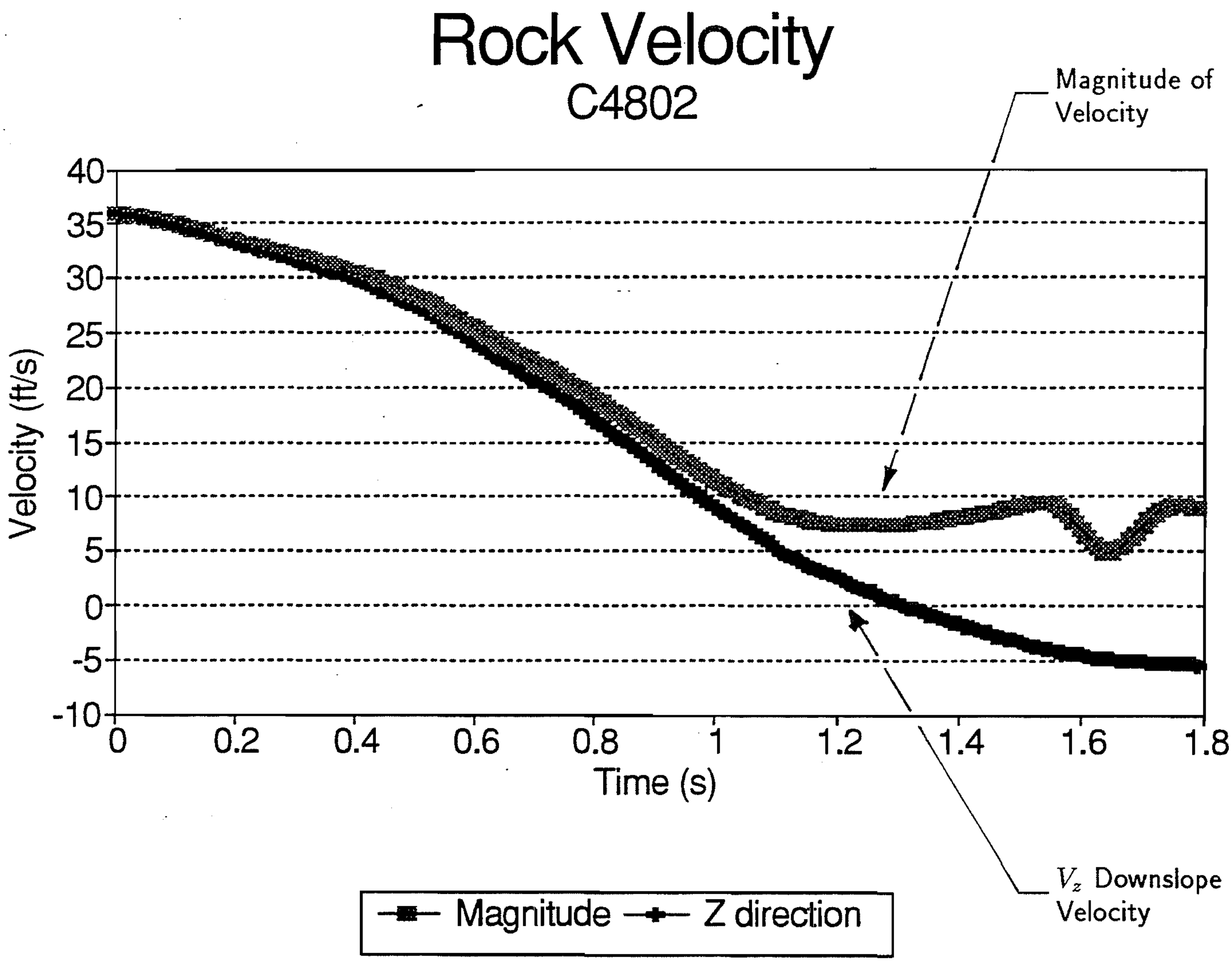


Figure III - 154
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model C

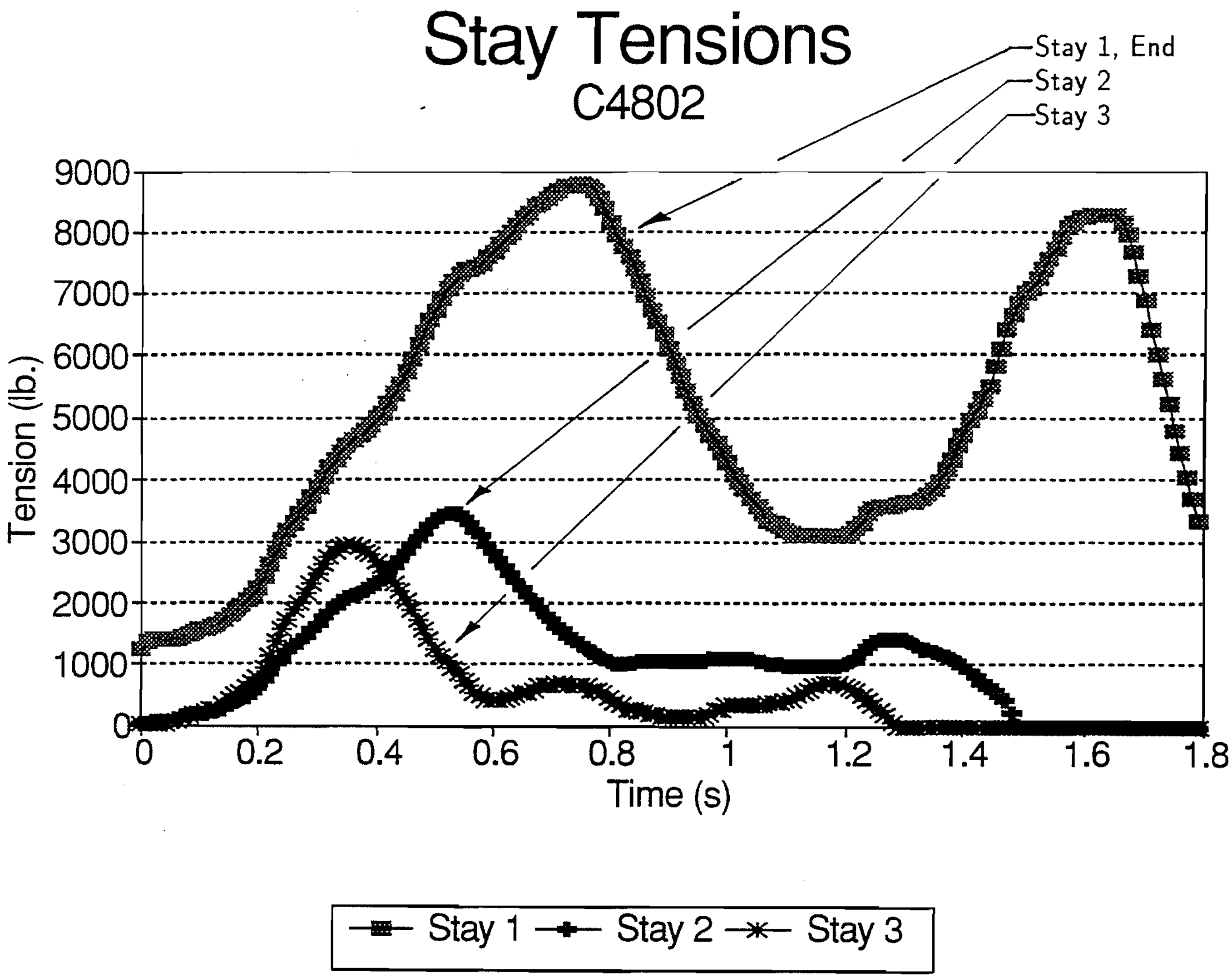


Figure III - 155
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model C

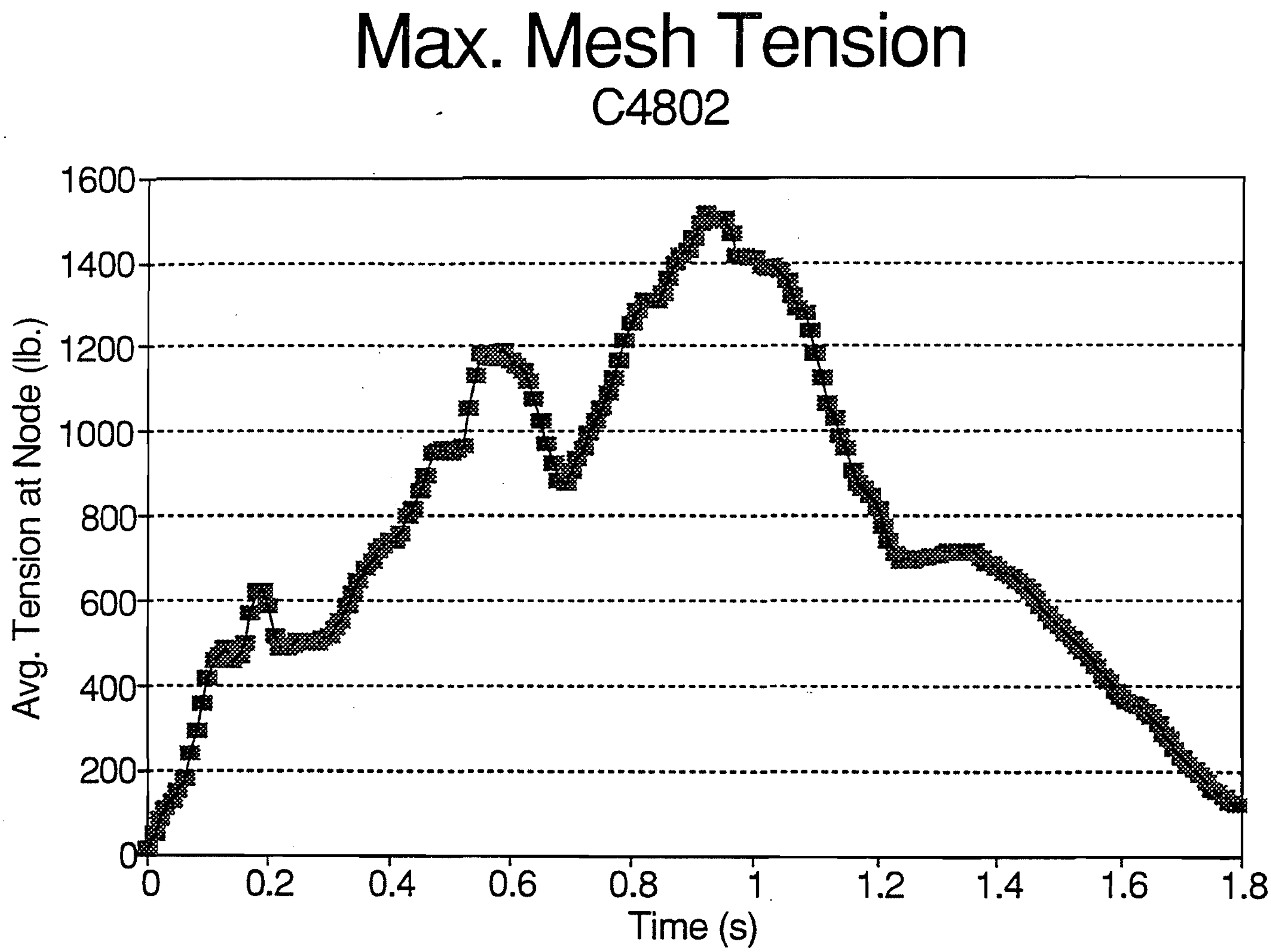


Figure III - 156
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model C

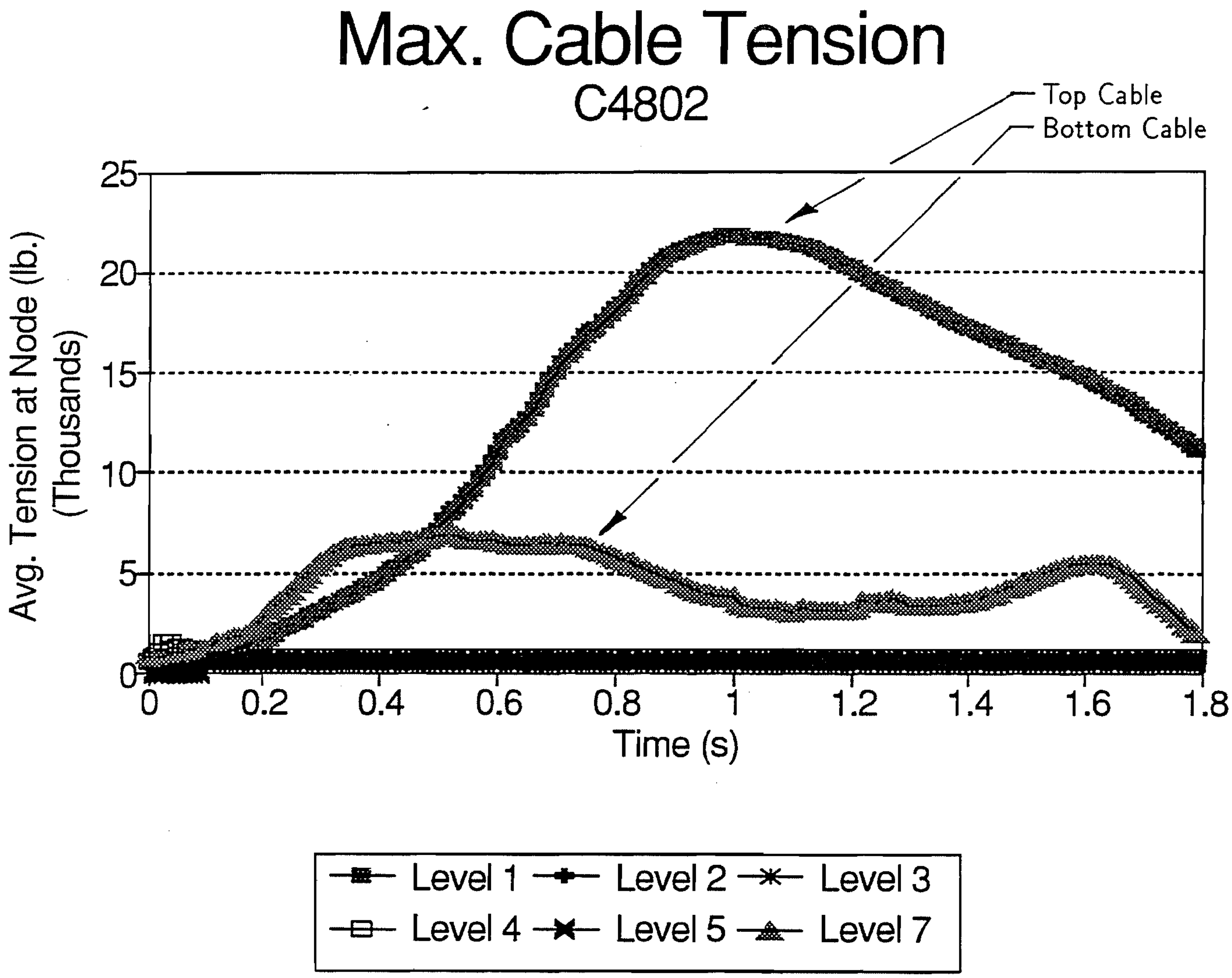
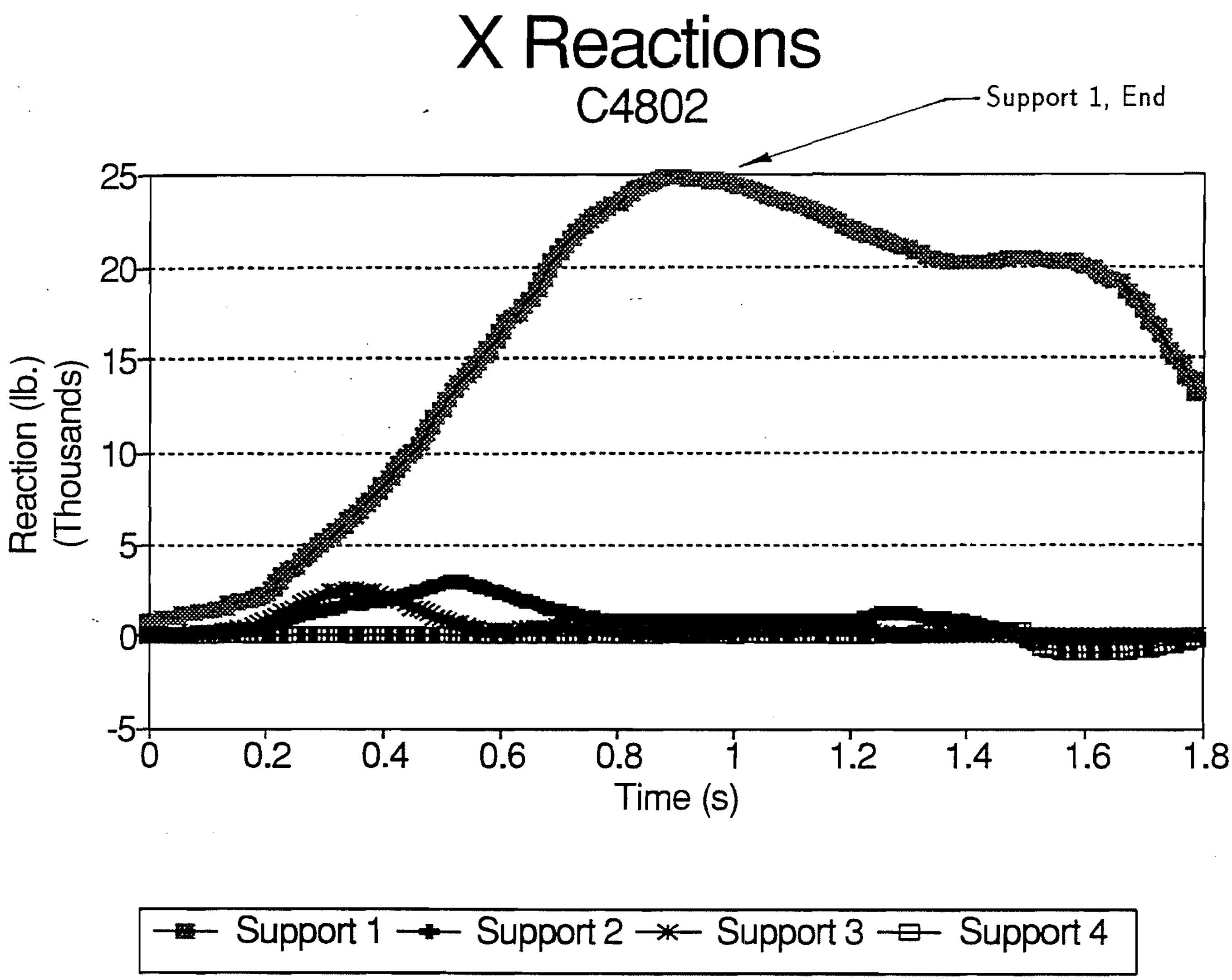
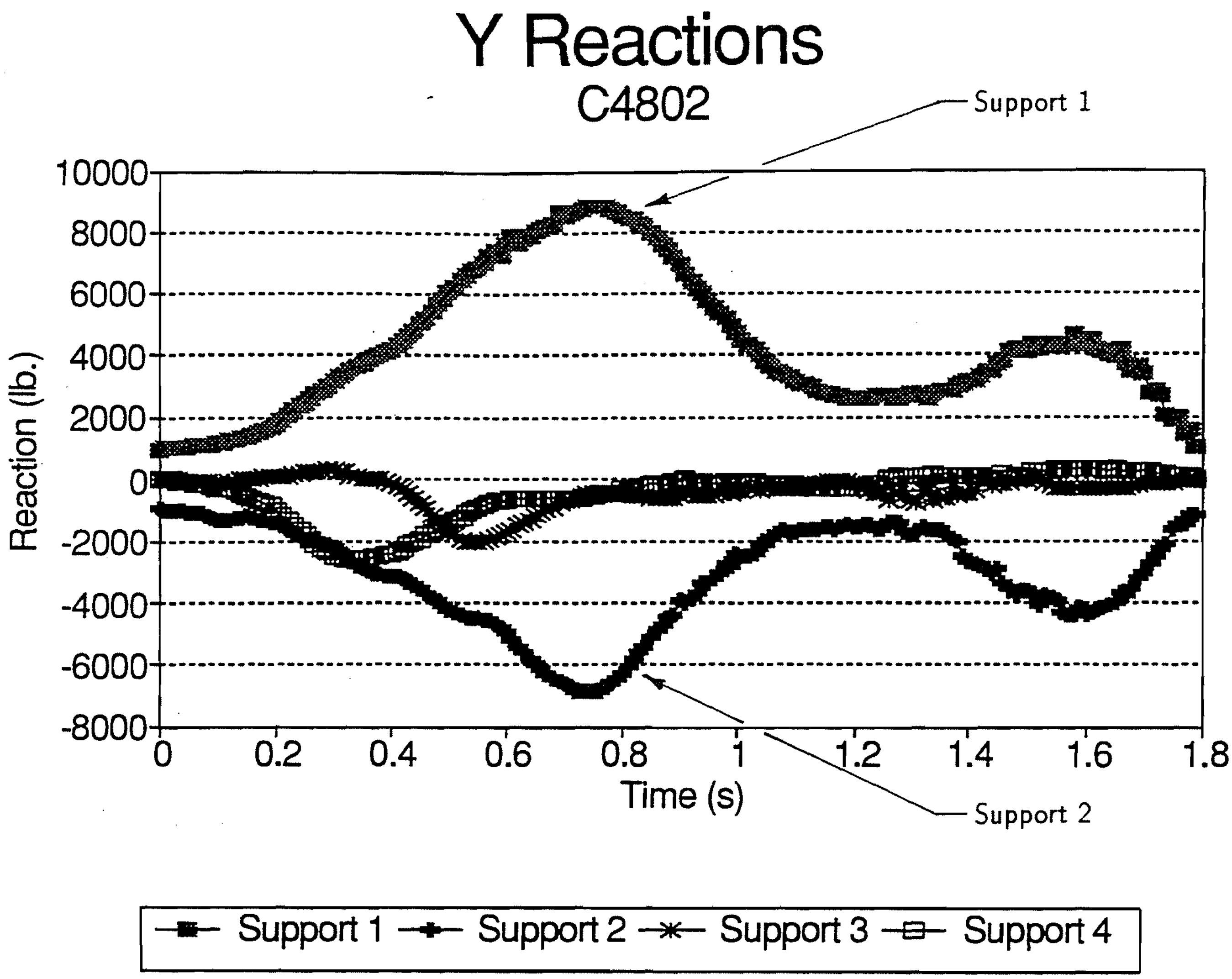


Figure III - 157
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model C



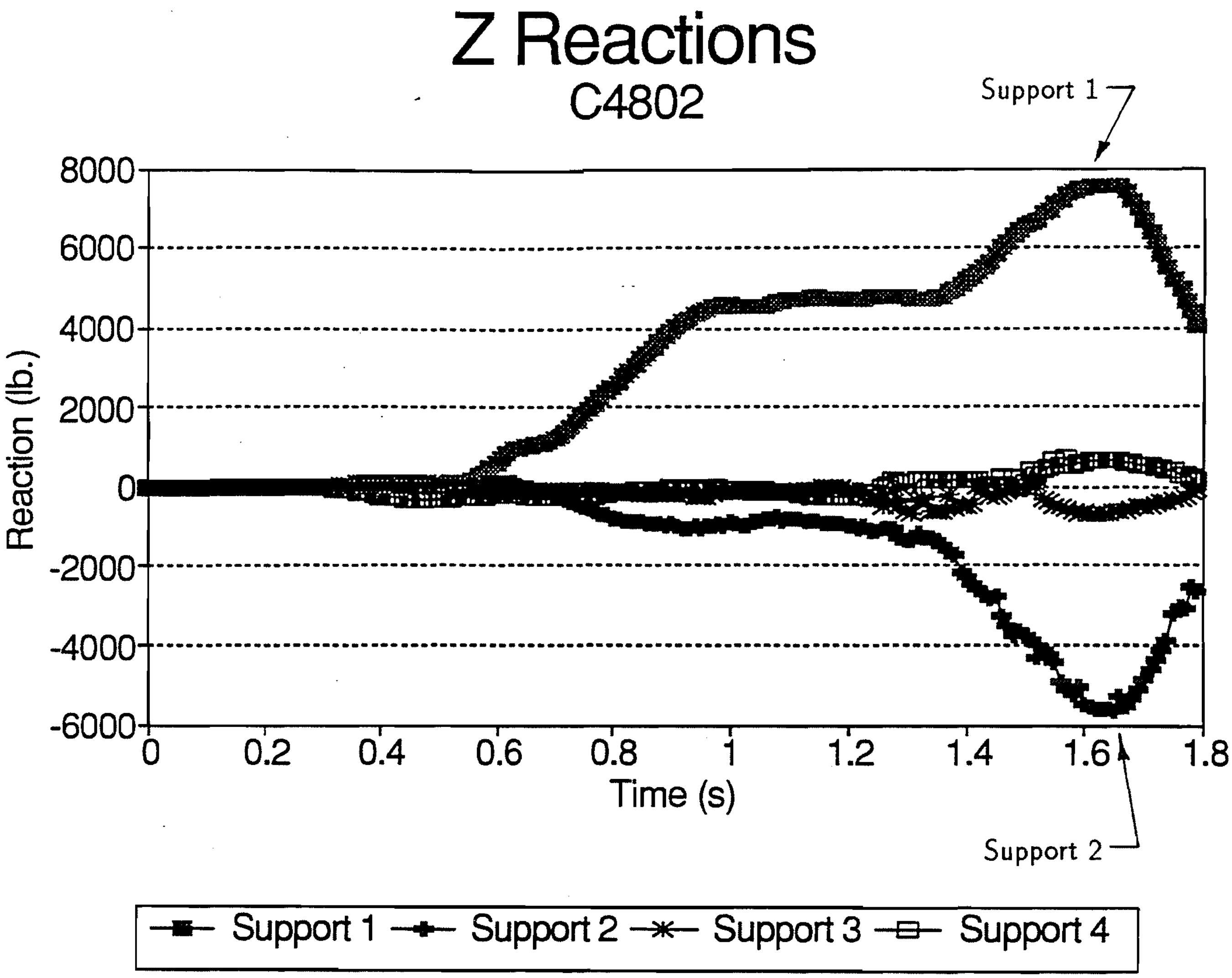
X Reaction, in-plane

Figure III - 158
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model C



Y Reaction, Vertical

Figure III - 159
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model C



Z Reaction, Downslope

Figure III - 160
Rockfall: 4,000 lbs. 80,000 ft-lbs
Model C

Appendix IV
Steel Fabric Materials

Gabion mesh has been used for Flexpost barriers since the first prototype was built and tested in 1989. The woven wire product offers excellent strength and flexibility at moderate cost. Early success with gabion mesh and the need to arrive at a workable barrier design in a limited time combined to discourage experimentation with other mesh materials. Other steel fabric constructions are available and two, cable net and chain link mesh, are used in rock fences and show promise for use on the Flexpost fence.

A survey of available mesh materials was made to seek steel wire constructions which might be used in Flexpost barriers. Manufactures of wire products listed in the Thomas Catalog were solicited for information on their products. Letters were sent to – manufacturers and many of these responded with product literature and samples. Wire products identified include:

Gabion Mesh

Single-wire, double-twist, woven wire product. Strong, flexible and tough construction. Double-twist weave limits the spread of damage when individual wires are ruptured. Widely used for rockfall protection in fences and in slope blankets.

Chain Link Mesh

Single-wire, single-twist, woven wire product. Available in many wire gages and cell sizes. Widely-used, widely-available product. In use for rockfall protection in fences and slope blankets.

Cable Nets (standard)

Nets of wire rope joined by mechanical fasteners; not woven. Available in several standard rope diameters and cell sizes. Cable nets are used on the strongest (and most expensive) rock fences.

Cable Nets (custom)

Custom fabrications of cable nets are available, including nets with large cable diameter.

Custom nets are routinely manufactured for military applications such as crash nets on aircraft carriers and submarine nets. Heavy custom nets have been used for rockfall protection.

Wire Cloth

Single wire, crimped, woven wire product. Wide application in industrial uses, especially as filter cloths in chemical processing. Wire cloth products range form light gage products such as pipe screens to heavy, rigid mats constructed of 1" diameter bars. Standard wire cloth products may be too stiff for use with Flexpost fences.

Wire Belts

A wide variety of woven and link-belt products of wire or strip steel used in machinery. Heavy and very strong. May be suitable for some rockfall applications.

A list of manufactures of wire products follows in Figures IV-1 and IV-2.

Rockfall Fence Products -- Address List

CHAIN LINK FENCE

Company	Address	City	ST	Zip	Contact	Phone	Ext.	Products	ASTM
American Fence Corporation	P.O. Box 6633	Phoenix	AZ	85005		602-272-6606		Galvanized, PVC option	A392
Anchor Fence	6500 Eastern Ave.	Baltimore	MD	21224	Bill Ulrich	301-633-6500		Galv., "Permafused" vinyl coated, colors	A641-71a
USS Cyclone Fence	13535 S. Torrence Ave.	Chicago	IL	60633		800-CYCLONE		Galv., Alum., "GALFLAN" coating, PVC	A491
Page Fence	100 Monongahela St. Dept. 104	Monassen	PA	15062		412-682-4000		Aluminized	A491
Security Fabricators	321 Lafayette Ave.	Kenilworth	NJ	07033		201-272-9171		Aluminum Fence	B211
Semmerling	P.O. Box 26A	Wheeling	IL	60090		800-338-7685		Galvanized, PVC, colors	
Robertson Fence	106 Shade Lane	Mt. Sterling	OH	43143		614-877-4354		Galvanized	
Hegarty and Sons	295 Skyline Dr.	Easton	PA	18042		215-252-8100		Galvanized, Aluminized, PVC	
Williams Fencing	Box 74, Route 9W	Ulster Park	NY	12487		914-338-1699		Large variety of fence materials	
Maryland Wire Belts	Rte. 16W	Church Creek	MD	21622	David Brown	301-228-7900		Security and special weave fences	
Hartford Wire Works	Box 550	Windsor	CT	06095		203-688-8148			
Georgia Pacific Buil.Prod.Div.	133 Peachtree St, N.E.	Atlanta	GA	30303		800-447-2882	Op#1		
D and B Products/Wire Div.	Box 1584-T, Landaff Rd.	Easton	MD	21601		301-822-5511		Chain link in multiple mesh sizes	
Rome Iron Group	Lynch Street	Rome	NY	13440		315-337-9000		Security Fence	
Pacific Fence and Wire	P.O. Box 125-T	Clackamas	OR	97015		800-547-2410			
Keystone steel and Wire	7000 SW Adams St. Dept. TR	Peoria	IL	61641		309-697-7020			

GABIONS

Company	Address	City	ST	Zip	Contact	Phone	Ext.	Products	ASTM
Maccaferri	3650 Seaport Blvd.	W. Sacramento	CA	95691	Peter Pasarelli	916-371-5805		Double twist hex. weave galv., PVC option	
Terra Aqua	P.O. Box 7546	Reno	NV	89510	Gary Osendorf	702-828-1390		Galvanized and plastic coated gabions	
F.P. Smith Wire Cloth	10110 Pacific Ave.	Franklin Park	IL	60131	John Zurliene	800-323-6842		Custom mesh including gabions	

WIRE MESH

Company	Address	City	ST	Zip	Contact	Phone	Ext.	Products	ASTM
Riverdale Mills	130-T Riverdale St.	Northbridge	MA	01534		508-234-8715		Vinyl coated steel wire mesh	
Argus Steel Products	P.O. Box 25133	Richmond	VA	23260		800-368-2082		Wide variety of meshes and metals	
Cooler Wire Products	5025-T N. River Rd.	Schiller Park	IL	60176		708-678-8585	5		
National-Standard Woven Prod.	P.O. Box 1620-T	Corbin	KY	40701		800-354-7844		Woven and non-woven metal fabrics	
McNichols Co.	1951-T Lively Blvd.	Elk Grove Village	IL	60007		800-237-3820			
Otto York Co.	P.O. Box 3100	Parsippany	NJ	07054	Thomas Poole	800-524-1543			
Tetko, Inc.	333 S. Highland Ave.	Briarcliff Manor	NY	10510	Ayesha Mayadas	914-941-1017		2 to 635 mesh	
Buffalo Wire Works	P.O. Box 129-T	Buffalo	NY	14240		716-826-4666			
Daniel, Gerard, and Co.	1-5 Plain Ave.	New Rochelle	NY	10801		914-235-2525		2 to 2800 mesh - all metals	
Ohio Fabricators	109 N. 14th St.	Coshocton	OH	43812		614-622-5922		Fabricated Wire Screen	
West End Wire Co.	1301 4th Ave.	Coraopolis	PA	15100		412-262-9473		Custom welded wire grids	
Great American Steel Equip.	P.O. Box 157	Maspeth	NY	11378		718-417-8900		Wire Mesh	
C.E. Sheperd Co.	P.O. Box 9445-TR	Houston	TX	77261		713-928-2324		PVC coated wire mesh	
Wire Crafters	6208 Strawberry Lane	Louisville	KY	40214		502-363-6691		Heavy gage indust. grade woven wire mesh	
Estey Wire Works	134 W. Central Blvd.	Palisades Park	NJ	07650		201-944-2828			

WIRE CLOTH

Company	Address	City	ST	Zip	Contact	Phone	Ext.	Products	ASTM
Trans World Pacific Corp.	2133 Fourth St.	Berkeley	CA	94710		800-227-1570			
The Wire Cloth Co.	14313 Wyoming St.	Detroit	MI	48238		313-934-7176		Opening 1" to 8" wide	
Howard Wire Cloth	28976A Hopkins St.	Hayward	CA	94545		415-887-8787		Up to 120" mesh	
L.E. Jones Wire Cloth	7920 Stansbury Rd.	Baltimore	MD	21222		301-285-5646			
Rotex Wire Cloth	1384 Knowlton St.	Cincinnati	OH	45223		800-243-8160			
Phoenix Wire Cloth	P.O. Box 610, Dept TR	Troy	MI	48099		800-458-3286			
Hillside Wire Cloth	1-T Main Ave.	Passaic	NJ	07055		800-826-7395		Up to 4" opening	
Cleveland Wire Cloth	3576 East 78th St.	Cleveland	OH	44105	Carmela Scali-Cel	800-321-3234			
Texas-North Star Wire Cloth	P.O. Box 1386	Stafford	TX	77497		800-231-0589			
Samco Sales, Inc.	6841-T Fulton	Houston	TX	77022		713-697-2773			
Universal Wire Cloth	16 N. Steel Rd.	Morrisville	PA	19067		800-523-0575			
W.S. Tyler, Inc.	P.O. Box 8900, Dept. T	Gastonia	NC	28053		800-238-9537			
Western Wire/Colorado	11155 E. 45th Ave.	Denver	CO	80239		800-338-1830			

INDUSTRIAL NETTING

Company	Address	City	ST	Zip	Contact	Phone	Ext.	Products	ASTM
International Cordage	1657-T W. 16th St.	Long Beach	CA	90813		800-628-9376		Custom nets for milit., indust., and marine. appl.	
Jason Mills, Inc.	1034-T River Rd.	Edgewater	NJ	07020		201-224-0004	48		
Apex Mills Corp.	P.O. Box 149	Inwood	NY	11969		516-239-4400			
Mid Lakes Corp.	P.O. Box 5320T	Knoxville	TN	37928	David Stair	615-687-7341			
Sterling Net Co.	16 Label St.	Montclair	NJ	07042		800-342-0316		Net fences	
Carron Net Co.	P.O. Box 177	Two Rivers	WI	54241					
Darjames Deniers	RR#1 Box 480, East Hill Rd.	Jeffersonville	NY	12748		914-482-3876			
Tensar Polytechnologies	1210 Citizens Pkwy	Morrow	GA	30260		800-845-4453		Structural and fence netting	

94-1	Comparison of the Hamburg Wheel-Tracking Device and the Environmental Conditioning System to Pavements of Known Stripping Performance
94-2	Demonstration of a Volumenteric Acceptance Program for Hot Mix Asphalt in Colorado
94-3	Comparison of Test Results from Laboratory and Field Compacted Samples
94-4	Alternative Deicing Chemicals Research
94-5	Large stone Hot Mix Asphalt Pavements
94-6	Implementation of a Fine Aggregate Angularity Test
94-7	Influence of Refining Processes and Crude Oil Sources Used in Colorado on Results from the Hamburg Wheel-Tracking Device
94-8	A Case Study of concrete Deck Behavior in a Four-Span Prestressed Girder Bridge: Correlation of Field Tests Numerical Results
94-9	Influence of Compaction Temperature and Anti-Stripping Treatment on the Results from the Hamburg Wheel-Tracking Device
94-10	Denver Metropolitan Area Asphalt Pavement Mix Design Recommendation
94-11	Short-Term Aging of Hot Mix Asphalt
94-12	Dynamic Measurements or Penetrometers for Determination of Foundation Design
94-13	High-Capacity Flexpost Rockfall Fences
94-14	Preliminary Procedure to Predict Bridge Scour in Bedrock (Interim Report)
95-1	SMA (Stone Matrix Asphalts) Flexible Pavements

93-1 Dense Graded Concrete
93-2 Research 92- Reality and Vision, Today and Tomorrow (Status Report)
93-3 Investigation of the Modified Lottman Test to Predict the Stripping Performance of Pavements in Colorado
93-4 Lottman Repeatability
93-5 Expert System for Retaining Wall System Phase I
93-6 Crack Reduction Pavement Reinforcement Glasgrid
93-7 A Case Study of Elastic Concrete Deck Behavior in a Four Panel Pre-stressed Girder Bridge Finite Element Analysis
93-8 Rehabilitation of Rutted Asphalt Pavements (Project IR-25-3(96)
93-9 Cold Hand Patching
93-10 Ice Detection and Highway Weather Information Systems, FHWA Experiment Project No. 13
93-11 Comparison of 1992 Colorado Hot Mix Asphalt With Some European Specification
93-12 Curtain Drain
93-13 Type T Manhole (Experimental Feature)
93-14 Interim Report for the HBP QA/QC Pilot Projects Constructed in 1992
93-15 SHRP Seasonal Monitoring Program in Delta
93-16 DOT Research Management Questionnaire Response Summary
93-17 Inservice Evaluation of Highway Safety Devices
93-18 Courtesy Patrol Pilot Program
93-19 I-70 Silverthorne to Copper Mountain: A History of Use of European Testing Equipment
93-20 Analytical Simulation of Rockfall Prevention Fence Structures
93-21 Investigating Performance of Geosynthetic-Reinforced Soil Walls
93-22 Influence of Testing Variables on the Results from the Hamburg Wheel-Tracking Device
93-23 Determining Optimum Asphalt Content with the Texas Gyratory Compactor

92-1 Colorado Department of Transportation Asphalt Pavement White Paper
92-2 Expansive Soil Treatment Methods in Colorado
92-3 Gilsonite An Asphalt Modifier
92-4 Avalanche Characteristics and Structure Response - East Riverside Avalanche Shed highway 550, Ouray County Colorado
92-5 Special Polymer Modified Asphalt Cement - Interim Report
92-6 A User Experience with Hydrain
92-7 Chloride Content Program for the Evaluation of Reinforced Concrete Bridge Decks
92-8 Evaluation of Unbonded Concrete Overlay
92-9 Fiber Pave, Polypropylene Fiber
92-10 Description of the Demonstration of European Testing Equipment for Hot Mix Asphalt Pavement
92-11 Comparison of Results Obtained From the French Rutting Tester With Pavements of Known Field Performance
92-12 Investigation of the Rutting Performance of Pavements in Colorado
92-13 Factors That Affect the Voids in the Mineral Aggregate In Hot Mix Asphalt
92-14 Comparison of Colorado Component Hot Mix Asphalt Materials With Some European Specifications
92-15 Investigation of Premature Distress in Asphalt Overlays on IH-70 in Colorado