14-1A RESTRAINER MATERIAL PROPERTIES AND DESIGN

Introduction

Bridge Memo to Designers (MTD) 20-4 requires hinges to remain seated during seismic events. In order to meet this requirement hinge restrainers are often used. An ideal restrainer should possess material properties that allow it to resist applied forces, restricts the movements of bridge segments, dissipates energy, and returns the structure segments to their relative pre-earthquake positions. However, in order to ensure proper functioning of the restrainers and to prevent their premature failure, all of the components in the restrainer system must be designed and installed properly.

The restrainer design method described in Bridge Design Aids (BDA) 14-1 requires the restrainer to remain within the elastic range utilizing only the restrainer's spring-like ability while seismic energy is dissipated by the plastic hinging of the columns. These criteria make cables more practical than bars because the cable has a longer elastic range and thus, shorter restrainers can be used. However, bars may be considered in some situations when improved serviceability or a high initial stiffness is required. Therefore, the stress-strain properties of both bars and cables are useful for developing practical systems.

Design of Retrofitting Devices

Earthquake restrainer devices should fail in a ductile rather than brittle manner when subjected to ultimate loading. Therefore, non-ductile components such as brackets, connections, and anchorages should be at least 25 percent stronger than the ductile cables or rods. In addition, brackets and connections should be designed so that they will not fail if some of the restrainer cables or rods in the unit are misadjusted or fail prematurely.

Restrainers at hinges and bearings should also have redundancy to account for possible defects in some of the units (faulty fabrication, installation, adjustment and maintenance, etc.) that may cause them to fail sooner than expected.

Impact design considerations become more significant when shorter bar restrainers are used due to the bar's high initial stiffness. This characteristic is effective in protecting the bearings during moderate events. The anchorages and superstructure should be investigated due to the stiffness of bar restrainers, their shorter length and the impact nature of seismic forces.

ATTACHMENT A

The following ultimate strengths should be assumed for designing connections and determining the adequacy of supporting members:

¾ inch cables F_u = 53 kips

$1^1/_4$ inch H.S. rods F_u = 188 kips

(use 53 x 1.25 = 66.2 kips and 188 x 1.25 = 235.0 kips per cable and rod, respectively)

Bolted connections shall be designed as a bearing type connection:

H.S. Bolts (A325)	Allowable Shear ($F_v = 0.6F_t$)	Allowable Tension ($F_t = \phi F_u$)
$^3/_4$"	20.5 kips	34.1 kips
$^7/_8$"	28.3 kips	47.1 kips
1"	37.1 kips	61.8 kips
$1^1/_8$"	40.1 kips	68.1 kips

Table A-1

Combined tension and shear: $F_{vc} = \sqrt{(F_v)^2 - (0.6 f_t)^2}$

F_{vc} = Allowable shear per bolt for combined shear and tension

ϕ = Reduction factor = 0.85

F_v = Allowable shear per bolt (kips)

f_t = Applied tension per bolt (kips)

F_u = Ultimate tensile strength based on lab tests

The following allowable stresses should be used for designing ASTM A-36 steel brackets for ultimate conditions:

Tension or compression	36,000 psi
Shear	26,000 psi

Bearing	$\frac{0.85\ w\ F_u}{t}$ or 3 x F_u whichever is smaller

Where:

t = thickness of plate

w = dimension of plate

F_u	58,000 psi
Groove welds	36,000 psi
Fillet welds	26,000 psi

Bearing plates for restrainer end anchorages should be sized to satisfy both bearing against the concrete surface and punching shear of the concrete member. The bearing resistance should be determined by the following expression:

$B = \phi$ x $0.85' f'_c$ x A_n

Where:

B = the calculated restrainer force

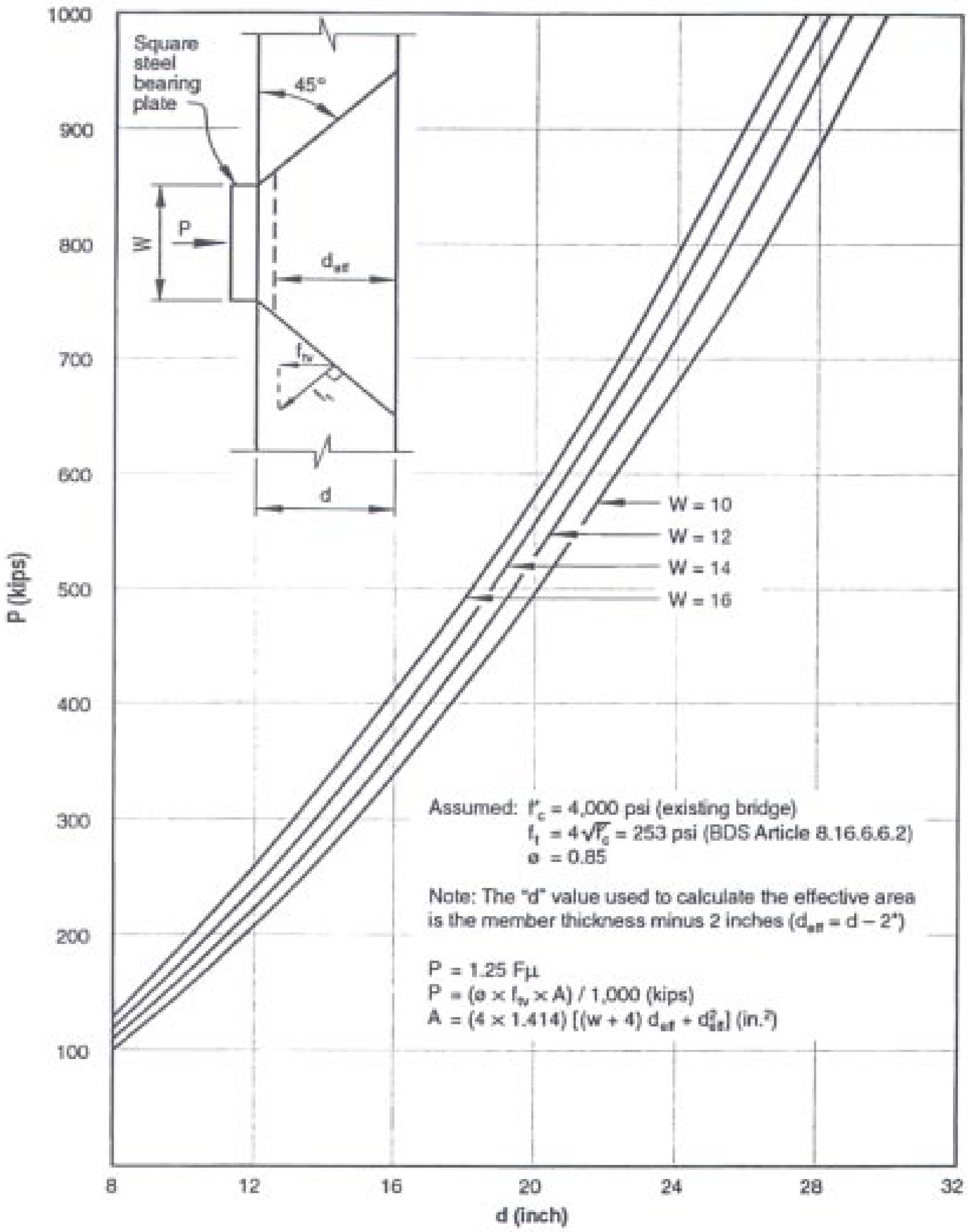
$\phi = 0.9$ (seismic)

$f'_c = 4{,}000$ psi

A_n = net bearing area (excluding the cored hole)

Punching shear plate size can be selected from the chart in Figure A-1.

ATTACHMENT A



Restrainer Materials Data

Three quarter inch cable, galvanized: See Standard Specifications, Section 75-1.035 - Bridge Joint Restrainer Units, for a full description.

Minimum ultimate tensile breaking strength = 46 kips.

$A_s = 0.222 \text{ in}^2$

E = 14,000,000 psi (minimum specified before yielding)

E = 18,000,000 psi (after initial stretching)

Load Factor Design: Assume yield strength = 85% x 46 = 39.1 kips

High strength bars, galvanized: Use ASTM A7-22 with supplementary requirements (the minimum elongation is 7 percent in 10 bar diameters).

Diameter Inches	Cross Sections Area Inches	Ultimate Strength (ksi)	Yield Strength (ksi)	Yield Strength (kips)
1"	0.85	150	120	102
1 $^1/_4$"	1.25	150	120	150
1 $^3/_8$"	1.58	150	120	190

Table A-2

E = 30,000,000 psi

Galvanizing may result in installation difficulties for high strength rods. Three types of rods are currently used - Dywidag rods, K&M smooth rods, and Mukosil rods. Dywidag rods are galvanized after being threaded. Therefore, the rod ends must be hot-brushed immediately after galvanizing. Even after this operation, placement of end nuts is difficult. K&M smooth rods are threaded after being galvanized. The ends are coated with zinc-rich paint after installation. If any damage to the galvanizing occurs, zinc-rich paint must be applied to the affected area.

Standard locking devices may not be effective on Dywidag or Mukosil rods. Set bolts positioned properly must be applied to prevent lock nuts from vibrating off rods.

Rods should be no longer than 30 feet. This is the standard stock length and galvanizing tanks will not accommodate lengths greater than this.

Bar Versus Cable Stress-Strain Properties

The load-elongation curves for bars and cables are shown in Figure A-2. The curves were obtained by tensioning specimens from near zero stress to the specified minimum yield stress (0.85 times the minimum breaking strength for cables) for 14 cycles and then to failure.

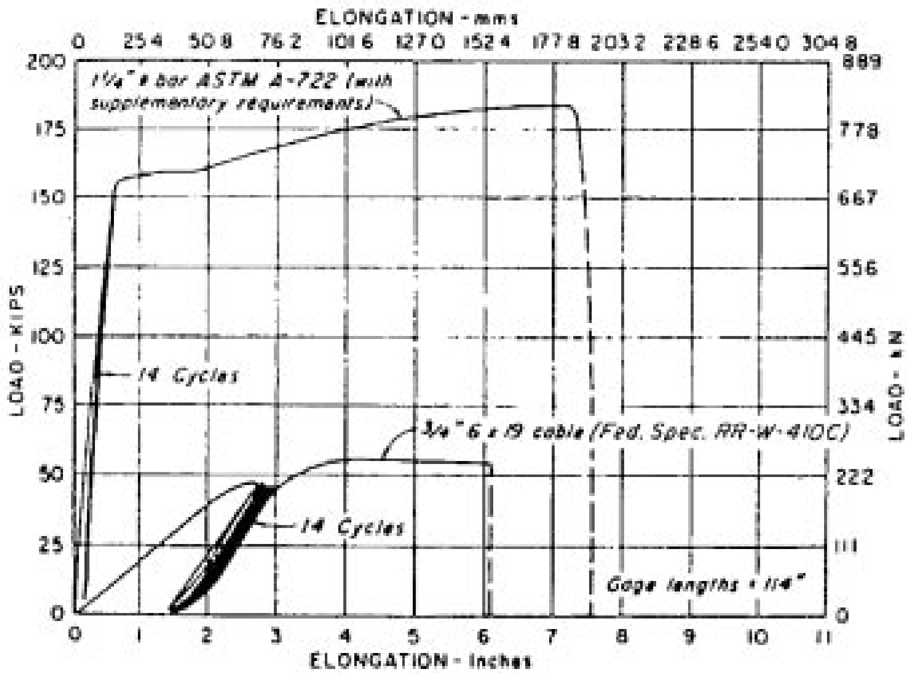


Figure A-2

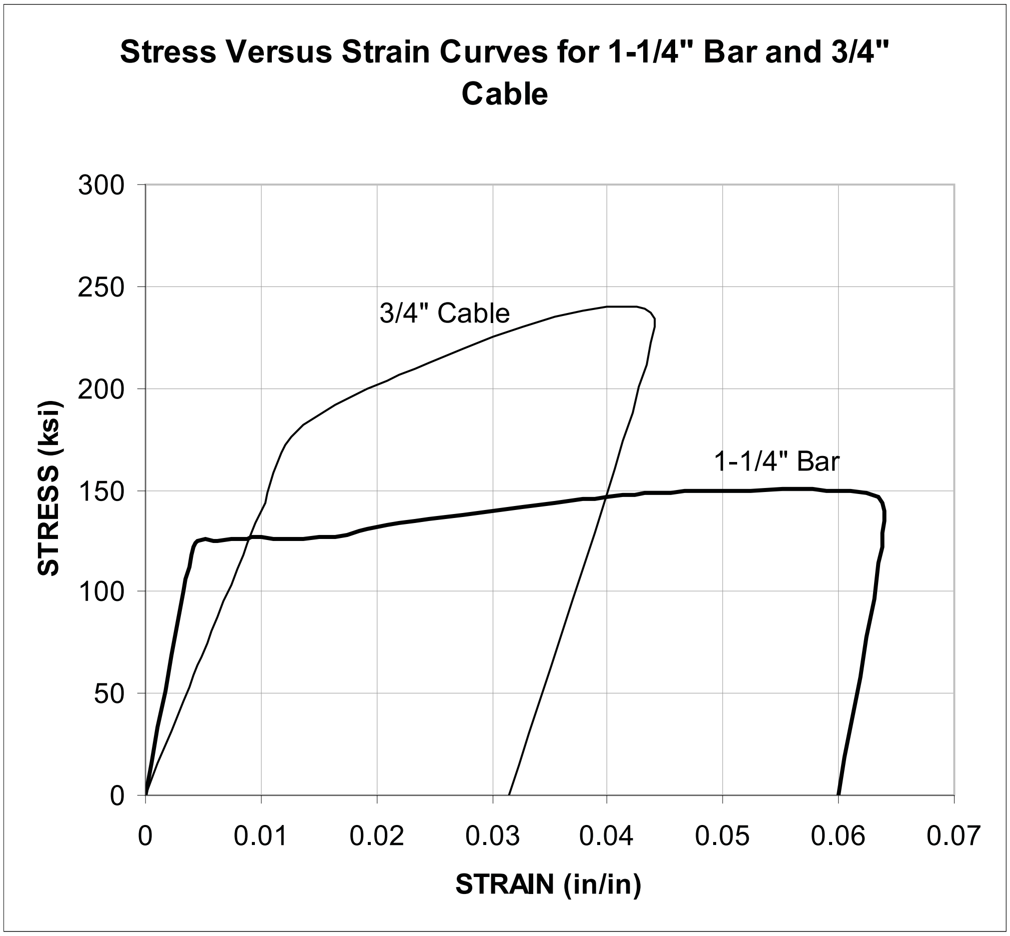


Figure A-3

The stress-strain properties shown in figure A-3 of cables and bars were obtained from the load enlongation curves in Figure A-2.

The area under the respective stress-strain curve up to the desired strain level represents the strain–energy dissipated by each material at that strain level. However, it should be noted that cable restrainers are designed to remain in the elastic range and the comparison with bar restrainers beyond the cable's yield strain should be avoided.

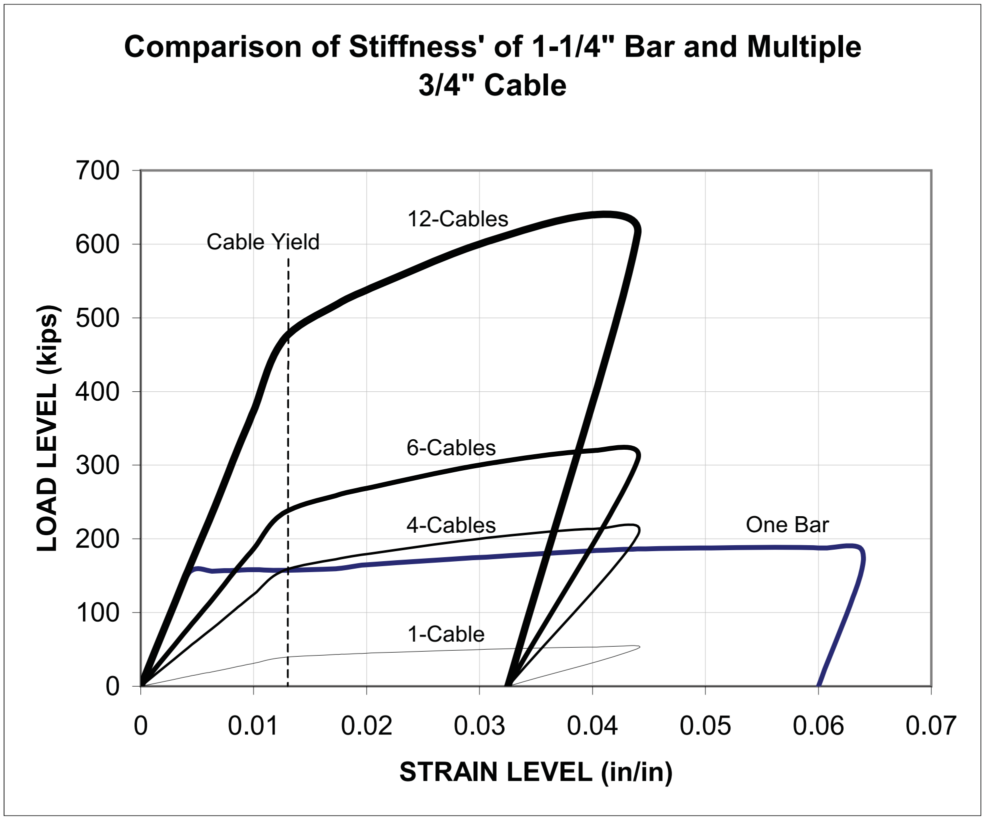


Figure A-4

In Figure A-4 it can be seen that four 3/4" cables provide a force level at yield approximately equivalent to one 1-1/4" bar. However, since restrainers should be designed to remain elastic, they should not be used to dissipate seismic energy. Comparisons between bars and cables are only significant at strains below the cable's yield strain.

Figure A-4 (Figure A-5 is an enlargement of Figure A-4 showing the cable's elastic range) shows load-strain curves for several combinations of cables and a single bar. From the figures, it can be seen that the elastic stiffness of one bar is equal to that of twelve cables, while the bar yields at a strain approximately 33% to that of a cable. In addition, four cables have a stiffness equivalent to the secant stiffness of a bar at the cable's yield strain. The relatively high stiffness of a bar allows it to provide a significant force at small displacement levels making them more efficient than cables in limiting relative hinge displacements. Furthermore, bars have a higher compression stiffness than cables, making the bars more resistant to kinking. The higher compression stiffness will also allow the bars to slide across the hinge more easily when it closes during a seismic event.

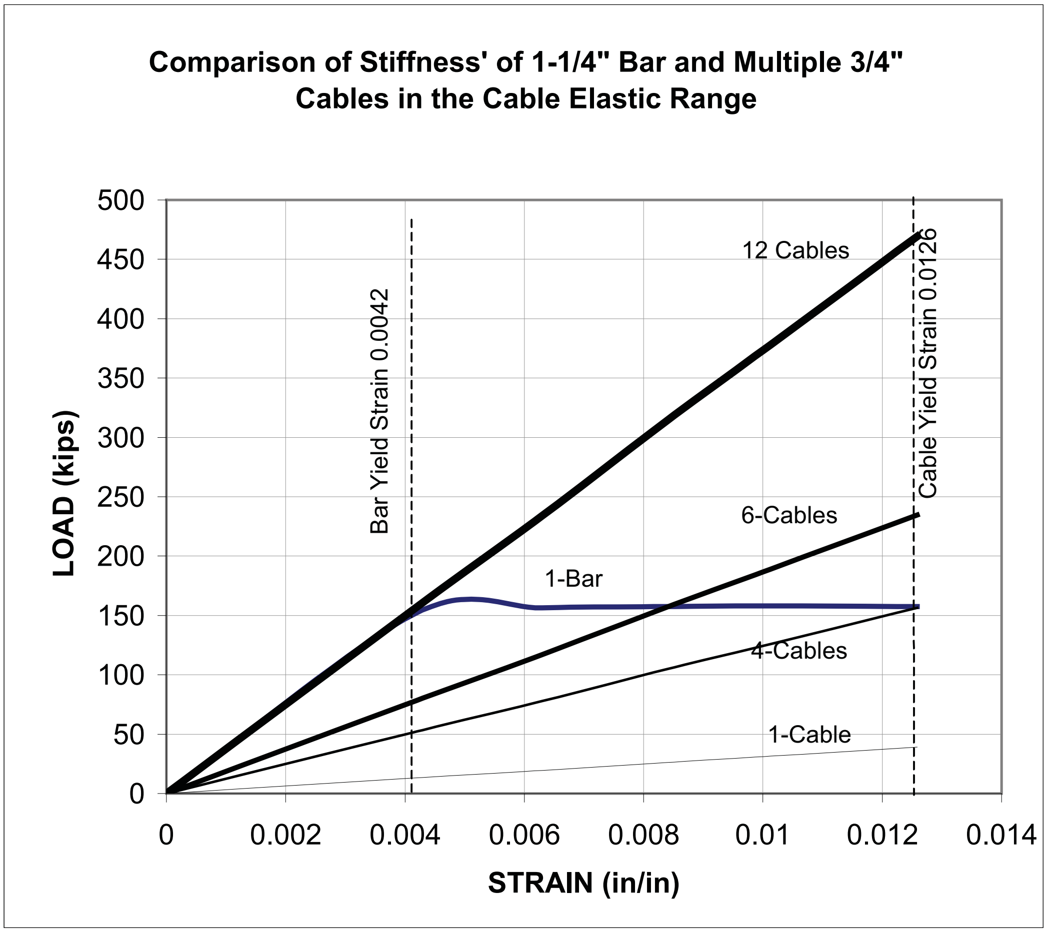

Comparison of Stiffness' of 1-1/4" Bar and Multiple 3/4" Cables in the Cable Elastic Range
LOAD (kips)
500
450
400
350
300
250
200
150
100
50
0
0
0.002
0.004
0.006
0.008
0.01
0.012
0.014
STRAIN (in/in)
Bar Yield Strain 0.0042
Cable Yield Strain 0.0126
12 Cables
6-Cables
1-Bar
4-Cables
1-Cable

Figure A-5