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U-BAR RESTRAINT ELEMENT (TYPE 11) FOR THE ANSR-II PROGRAM

by
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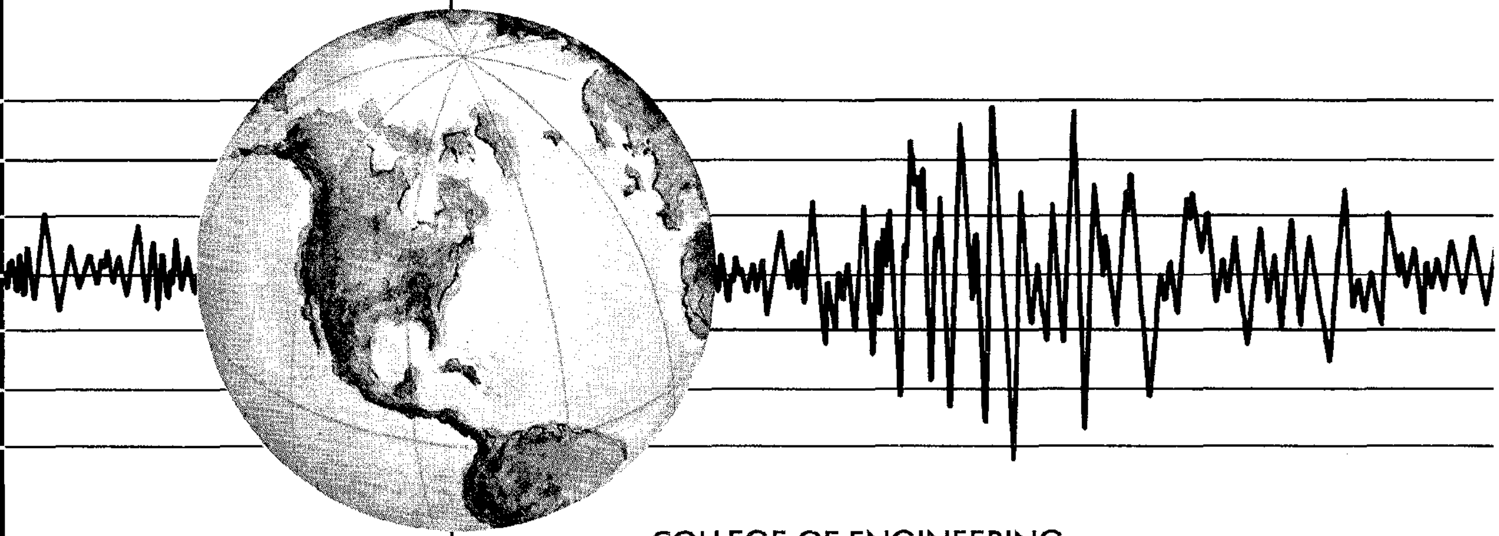

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This report describes a U-bar piping restraint element for the ANSR-II program. The element is intended for use primarily in analyses of pipe whip but can be used to model any uniaxial restraining device which provides inelastic restraint to structural motion in one direction (tension) while allowing unrestrained motion in the other direction (compression).

The report contains a description of the element behavior, the theoretical formulation, and a computer program user's guide.

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U-BAR RESTRAINT ELEMENT (TYPE 11)
FOR THE ANSR-II PROGRAM

by

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ABSTRACT

This report describes a U-bar piping restraint element for the ANSR-II program. The element is intended for use primarily in analyses of pipe whip but can be used to model any uniaxial restraining device which provides inelastic restraint to structural motion in one direction (tension) while allowing unrestrained motion in the other direction (compression).

The report contains a description of the element behavior, the theoretical formulation, and a computer program user's guide.

ACKNOWLEDGEMENT

The element described in this report was developed as part of work conducted for the Lawrence Livermore Laboratory under Subcontract 3371609.

This report is not a report to the sponsor. The material contained in this report will be incorporated into a project report at a later date.

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1. INTRODUCTION

This report describes an ANSR-II element [1] for modelling U-bar pipe whip restraints of General Electric type (Fig. 1). The element has the following features:

1. Idealization as an inelastic bar, arbitrarily oriented in space. Resistance along restraint axis only (Fig. 1).
2. Multi-linear force-extension relationship in tension (up to 6 linear segments), with initial gap. Inelastic unloading. Zero stiffness in compression.
3. Option for large displacement analysis, to allow for change in direction of restraint axis.
4. Anchorage to either a fixed point or to a node at some other point on the structure.
5. Option for pipe displacements perpendicular to U-bar plane to be ignored, to allow unrestrained axial movement of pipe.

This report contains a description of the element and a user's guide.

2. ELEMENT PROPERTIES

2.1 GENERAL CHARACTERISTICS

A restraining device in the form of a U-bar has been proposed for use as a pipe whip restraint by the General Electric Company. The device is illustrated diagrammatically in Fig. 1.

For analysis, the restraint is idealized as an inelastic bar, as shown in Fig. 2. The bar possesses only axial stiffness and exerts a restraining force only along the axis of the restraint. This is a simplified idealization which ignores such effects as bending of the U-bar and friction between the U-bar and the pipe. The idealization may be inaccurate if the pipe displacement is not parallel to the initial U-bar axis.

A restraint element may be arbitrarily oriented in space. The orientation is defined by specifying two nodes at the element ends (Fig. 2). Node I is a node of the piping system. Node J will typically be a fixed anchor point (i.e. a node with specified zero displacements). However, node J may be a structural node if desired. If node J is fixed ("single node" option), the element extension depends on the displacements of node I only. If node J is not fixed, the element extension depends on the relative displacements between I and J, and restraint forces are exerted at both nodes. Two or more elements may be connected to a single pipe node if desired.

The relationship between axial force and axial extension is assumed to be multi-linear, with up to six linear segments (Fig. 3). The stiffness may increase or decrease with increasing extension. The stiffness in any segment may be negative, but must always be nonzero. The unloading stiffness is always assumed to be the largest of the loading stiffnesses.

In practice, U-bar restraint elements may be quite short in length, so that displacements of the pipe which are not parallel to the initial restraint axis may produce substantial rotations of the element axis. That is, for structural analysis purposes the displacements may be large, and the influence of change in geometry must be taken into account. The user may specify that only small displacements (rotations) of the restraint be assumed or that large displacements be taken into account.

2.2 NORMAL DISPLACEMENT OPTION

Figure 4 shows a typical restraint in which the axis of the pipe is normal to the plane of the U-bar. In some cases, there may be significant pipe displacements along the pipe axis as well as in the U-bar plane.

When the large displacement option is used, the element extension is the difference between the current and initial element lengths. All displacements of the restrained node, including the component along the pipe axis, thus contribute to the calculated extension. If the U-bar is placed between collars on the pipe, then the bar will rotate as the pipe moves axially, and the calculated extension will be correct. However, if there are no collars present, the U-bar will not be affected by axial movements of the pipe. In particular, closure of the initial gap will be governed only by pipe movements in the U-bar plane.

To allow for this effect, an option is provided to allow node displacements normal to the U-bar plane (i.e. typically axial movements of the pipe) to be ignored, up to the time the initial gap closes.

Figure 4 shows a length of pipe and a U-bar restraint. The restraint element is defined by nodes I and J, as before. In addition, a third node, K, may be specified, such that the IJK plane is normal to the U-bar plane. Typically, the U-bar will be at right angles to the pipe, and node K will be a node on the pipe. The angle JIK will then be a right angle, and the direction of free movement will be along IK. More generally, K may be any point in the plane normal to the U-bar plane, as shown, in which case the free movement is along line IK', where K' is in the IJK plane and angle JIK' is a right angle. Point K' is determined automatically by the program.

If node K is specified to be nonzero in the input data, pipe displacements along IK' are ignored in computing the new axial length of the element. This is done until the new axial length exceeds the original length plus the clearance. The U-bar then functions to restrain the pipe. After this time, all pipe displacements are used to calculate the axial length of the element (that is, the bar is assumed not to slip along the pipe), until such time as the gap reopens.

2.3 STRAIN RATE DEPENDENCE

Viscous damping may be specified for the element, if desired, to introduce a simple form of strain rate dependence. If nonzero values are specified for factors β_0 and/or β_T, a viscous damper is introduced in parallel with the element. When the element gap is closed, the damping coefficient, C, is given by

$$C = \beta_0 K_1 + \beta_T K_T$$

where K_1 = stiffness of first segment, as shown in Fig. 3, and K_T = stiffness of current segment (K_1, K_2, etc., depending on restraint extension). The effect is to increase both the stiffness and strength of the element by amounts which depend on the rate of extension of the element. When the restraint is not active (i.e. before the gap closes), the value of C is set to zero.

Appropriate values of β_0 and β_T must be selected using experiment and experience.

2.4 STIFFNESS REFORMULATION TOLERANCE

With the ANSR-II strategy for nonlinear analysis, the structure stiffness matrix is modified only when changes occur in one or more elements. If the behavior of the structure is piecewise linear, as is often the case for small displacement analyses, the structure stiffness is modified only at each yield event. For large displacement analyses, the element stiffnesses change continuously, and hence the structure stiffness may be modified in every time step. In many cases, however, the stiffness change from one step to the next may be small, and it may be reasonable to retain the same stiffness for several steps. To allow this, the user may specify a stiffness reformulation tolerance to control the frequency of stiffness reformulation.

For the U-bar element, stiffness changes occur when the tangent stiffness changes and as the orientation of the element changes (large displacements option). The reformulation tolerance applies to the change of orientation. If the change of orientation is small, the stiffness change will be small and a modification of the structure stiffness will not be necessary. The reformulation tolerance is an angle. Each time the element stiffness is changed, the direction of the element is saved. If the angle between the current direction and the previous direction is less than the tolerance angle, the stiffness is not changed. An angle of about 0.1 radians is suggested.

3. THEORY AND COMPUTATIONAL PROCEDURE

3.1 ELEMENT STIFFNESS

The matrix of direction cosines of the line from node J to node I (Fig. 2) is

$$\underline{T} = < d_x \; d_y \; d_z > \tag{1}$$

where d_x, d_y, d_z = direction cosines with respect to the global X, Y, Z axes. For the large displacements option, the direction cosines are continually updated. For the small displacements option, they remain constant.

For any given state of the element, the current extensional stiffness, K, is determined (equal to zero for an open gap; one of the values K_1 through K_6 when the gap is closed). Hence, the element sitffness matrix, $\underline{K}$, for the "single node" case (node J fixed) is

$$\underline{K} = \underline{T}^T \cdot K \cdot \underline{T} \tag{2}$$

For the "two node" case (node J not fixed), the stiffness matrix, K', is

$$\underline{K}' = \begin{bmatrix} \underline{K} & -\underline{K} \\ -\underline{K} & \underline{K} \end{bmatrix} \tag{3}$$

3.2 EFFECTIVE DYNAMIC STIFFNESS

If nonzero values are specified for β_0 and/or β_T, the effective stiffness for dynamic analysis is determined following the standard ANSR-II procedure [1], except for the following modification. If the gap is closed, then the $\beta_0 K_0$ stiffness is determined using K_1 (Fig. 3). However, if the gap is open, the value $\beta_0 K_0$ is assumed to be zero. This is because it would clearly be incorrect to assume that damping is present in an inactive restraint. The element resisting forces due to damping are calculated using the same assumption.

3.3 GEOMETRIC STIFFNESS

For large displacement analysis, a geometric stiffness is included. If node J is fixed, the geometric stiffness matrix in terms of global translations of node I is

$$\underset{\sim}{K_G} = \frac{N_c}{\ell_c} \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{4}$$

where N_c is the current axial force and ℓ_c is the current length of the element.

If node J is not fixed, the geometric stiffness matrix in terms of global translations at I and J is

$$\underset{\sim}{K'_G} = \begin{bmatrix} \underset{\sim}{K_G} & -\underset{\sim}{K_G} \\ -\underset{\sim}{K_G} & \underset{\sim}{K_G} \end{bmatrix} \tag{5}$$

The matrix $\underset{\sim}{K_G}$ is not strictly correct for an "engineering" large displacement formulation. However, it is sufficiently accurate, and it is convenient to use because it is invariant with respect to element orientation.

3.4 STIFFNESS REFORMULATION

The stiffness reformulation code is set if (a) the extensional stiffness, K, changes or (b) the angle between the current restraint axis and the axis when the stiffness was last reformed exceeds the user-specified tolerance (the latter for the large displacement option only). The tolerance is exceeded if the dot product of the direction cosine vectors is less than the cosine of the tolerance angle.

3.5 DISPLACEMENTS NORMAL TO U-BAR PLANE

If node K is specified and the gap is open, the components of nodal displacement parallel to the IK' direction (Fig. 4) are ignored for calculating element deformations and direction cosines.

Let $\underline{T}_n$ be the direction cosine matrix of IK'. This matrix is calculated for the initial configuration and is assumed to remain constant during the analysis. For the "single node" option, let the vector of increments in nodal translations at I be $\underline{\Delta r}_I$. Then the components of displacement increment parallel to IK' are given by

$$\underline{\Delta r}_{IK} = \underline{T}_n^T \cdot \underline{T}_n \cdot \underline{\Delta r}_I$$

Hence, a modified displacement increment is calculated as

$$\underline{\Delta r}_I' = \underline{\Delta r}_I - \underline{\Delta r}_{IK}$$

This modified increment is used to calculate the element extension and to update the element orientation.

For the "two node" option, the procedure is applied to the displacements of both node I and node J.

4. USER'S GUIDE

U-BAR RESTRAINT ELEMENT (TYPE 11)

1. CONTROL INFORMATION - Two cards

1(a) First Card

Columns	Note	Name	Data
4- 5(I)		NGR	Element group indicator. Punch 11.
6-10(I)		NELS	Number of elements in group.
11-15(I)		MFST	Element number of first element in group. Default = 1.
16-25(F)	(1)	DKO	Initial stiffness damping factor, β_o.
26-35(F)		DKT	Tangent stiffness damping factor, β_T.
41-80(A)			Optional group heading.

1(b) Second Card

Columns	Note	Name	Data
1- 5(I)		NMST	Number of different property types.
10(I)		JFIX	Connection code. (a) Zero or blank: single node option. NODJ assumed fixed. (b) 1: two node option. NODJ assumed not fixed.

2. PROPERTY TYPES - Three cards per type

2(a) First Card: Control Information

Columns	Note	Name	Data
1- 5(I)		N	Type number, in sequence beginning with 1.
6-10(I)		NSEGG	Number of segments in force-extension relationship. Max. 6; Min. 2.
11-20(F)		DBB	Initial clearance.
21-30(F)	(2)	TOLL	Stiffness reformulation tolerance (radians). Suggested value = 0.1.

2(b) Second Card: Stiffnesses

Columns	Note	Name	Data
1-60(F)		SPSTT	Up to 6 fields, each 10 columns. Specify NSEGG stiffnesses (K_1, K_2, etc.-Fig. 3).

2(c) Third Card: Strengths

Columns	Note	Name	Data
1-50(F)		FFF	Up to 5 fields, each 10 columns. Specify NSEGG-1 strengths (F_1, F_2, etc.-Fig. 3).

3. ELEMENT DATA - NELS cards

Columns	Note	Name	Data
1- 5(I)		MEL	Element number.
6-10(I)		NODI	Node number I (Fig. 2).
11-15(I)		NODJ	Node number J.
16-20(I)		IMBT	Property type number.
25(I)		KGEOM	Large displacement code. (a) Zero or blank: small displacements. (b) 1: large displacements
30(I)		KOUT	Time history code. (a) Zero or blank: no output. (b) 1: output required.
31-35(I)	(3)	NODK	Node number K. Optional, to define normal direction.

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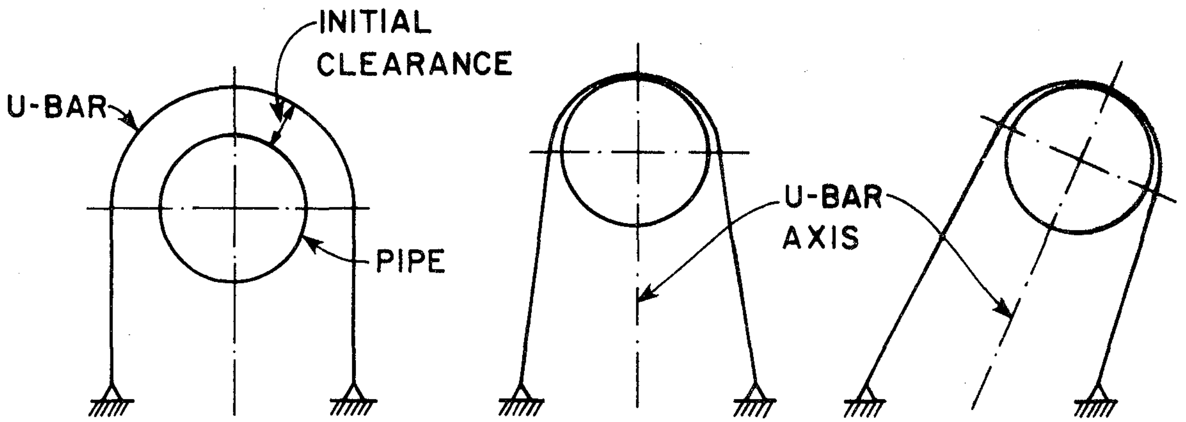


(a) BEFORE BREAK (b) AFTER BREAK

FIG. 1 U-BAR RESTRAINT (DIAGRAMMATIC)

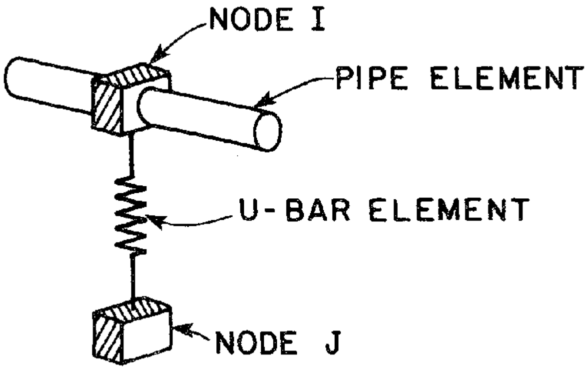


FIG. 2 IDEALIZATION FOR ANALYSIS

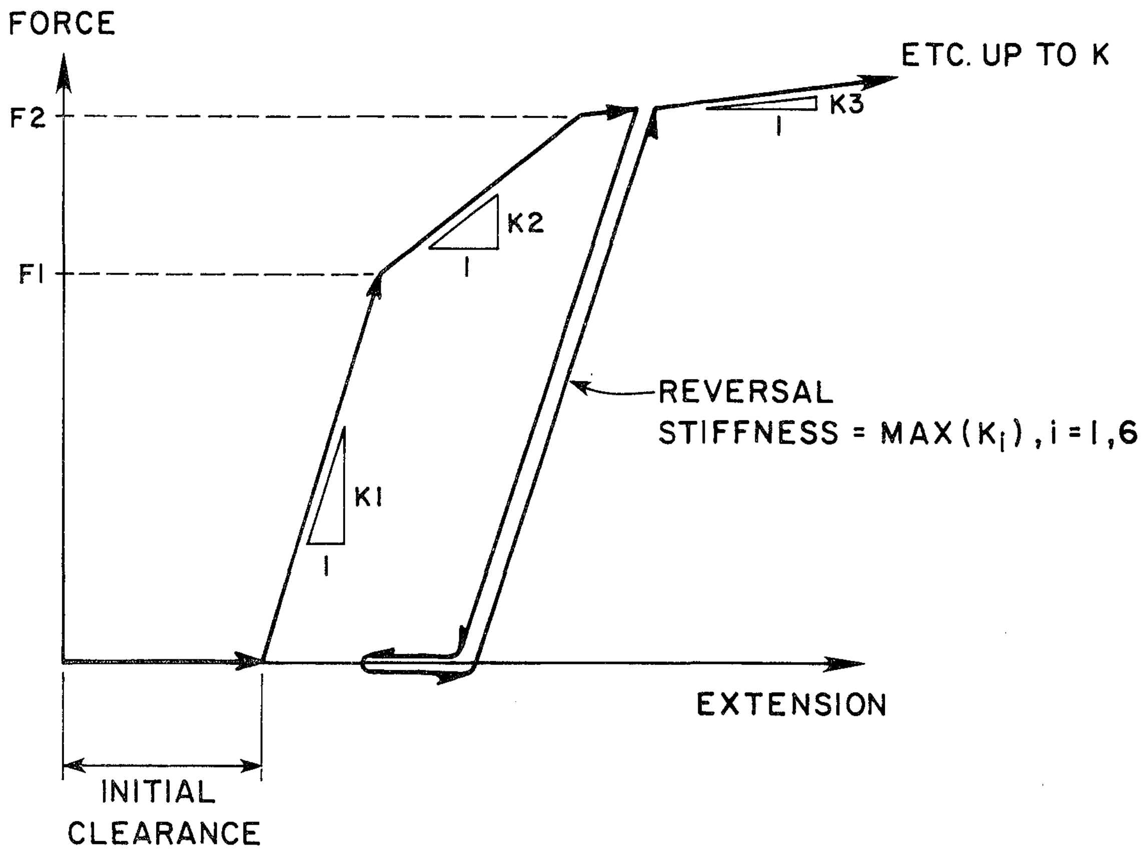
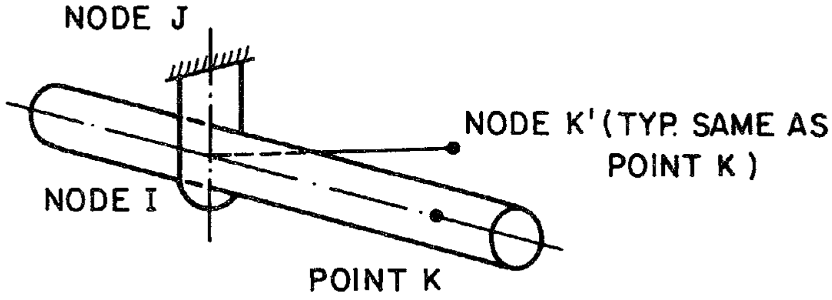


FIG. 3 FORCE-EXTENSION RELATIONSHIP



IJK' DEFINES NORMAL PLANE
IK PERPENDICULAR TO IJ

FIG. 4 NORMAL DISPLACEMENT OPTION

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