ON THE CONGRUENT FEATURE IN NASTRAN

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ABSTRACT

The congruent feature, which is a capability in NASTRAN that can contribute to significant increases in computational efficiencies, is discussed in this paper. The usage of the capability and the software design characteristics affecting it are explained. The factors affecting the efficiency of the feature are pointed out. The details pertaining to the software design of the congruent feature are presented; in particular, the congruent element table is described. Several examples employing the congruent feature are considered and comparisons of EMG (Element Matrix Generator) module CPU times with and without this feature are presented. The results of the paper clearly demonstrate the role of the congruent feature in increasing computational efficiencies and its applicability to large-size problems.

INTRODUCTION

An important step in any NASTRAN problem is the generation of element matrices (stiffness, mass, and damping matrices as required) in the EMG module. In many cases, this step can represent a significant portion of the total problem activity. Because of the differences in algorithms and procedures, the cost of generating the element matrices for an element depends on the element type, its configuration and its properties. However, this cost is associated primarily with CPU activity and is not significantly affected by core size or I/O transfers (Reference 1).

Normally, the element matrices are generated in the EMG module once for each element in the model. However, when two or more elements in the model have the same element matrices, there is no reason why the same matrices should be computed separately for each such identical element. By declaring such elements as congruent, it is possible to cause their element matrices to be computed only once for all elements in the congruent set instead of their being computed repeatedly for each of the individual elements in the set. This results, in general, in a saving of CPU time in the EMG module. In many cases, judicious formulation of the problem to facilitate the use of the congruent feature can result in substantial savings in the computational effort. In some problems, over 99 percent reductions in EMG module CPU times have been obtained.

The congruent feature is not yet adequately publicized in the NASTRAN documentation. Currently, it is only referenced in the NASTRAN User's Manual (Reference 2) with a one-page description of the CNGRNT bulk data card. It is hoped that the discussion of this feature herein will lead to more widespread use of this capability in large-size problems thus resulting in significant increases in computational efficiencies.

CONGRUENT FEATURE USAGE

The congruent feature is specified in NASTRAN by means of one or more CNGRNT cards in the Bulk Data Deck (Reference 2). Any number of such cards may be employed.

The CNGRNT bulk data card is an open-ended card and requires the specification of a primary element identification number and one or more secondary element identification numbers. (A description of the CNGRNT card is given in the Appendix.) The terms primary and secondary as used with regard to congruent data are purely relative and have no real significance. Generally, the primary element is the lowest numbered element in the congruent set, but this need not be so. The element matrices are computed in the EMG module only for the lowest numbered element in a congruent set (even though this element may not be the primary element). The element matrices for the rest of the elements in the congruent set are then derived from these computed matrices.

SOFTWARE DESIGN CHARACTERISTICS AFFECTING CONGRUENT FEATURE USAGE

When using CNGRNT cards, the user should be aware of the following important characteristics of the congruent capability software design in NASTRAN.

- User Responsibility for Congruency Specification

The elements declared as congruent must have characteristics (such as their orientation and geometry) that cause their element matrices in the global coordinate system to be truly identical. The program cannot test the validity of this structural specification. It is, therefore, the user's responsibility to ensure that element congruence specifications are valid. Improper congruence specifications will result in an improper structure definition and will in turn lead to erroneous results. It should be emphasized that the proper use of the congruent feature will not cause the answers to be any different from those obtained without the use of the feature, but will result in a saving of CPU time in the EMG module.

- Flexibility in Specifying Congruencies

Clearly, congruency by its very definition can apply only to elements of the same type. Thus, for instance, a bar element can be congruent only to another bar element and not to a plate element. However, because of the effective manner in which the congruent feature has been incorporated into NASTRAN (as will be evident from the discussion in a later section), elements of different types can be specified on the same logical CNGRNT card without in any way making the different element types congruent. Thus, on the same logical CNGRNT card, several bar elements can be declared as belonging to a congruent set and several plate elements can be specified as belonging to a separate congruent set. However, the user should ensure that such specifications do not lead to erroneous declarations when elements of different types have the same identification numbers.

- Provision of "Phantom" Element Identification Numbers

As a corollary to the above, it may be noted that the element identification numbers (primary or secondary) specified on a CNGRNT card need not all exist in a model. This facilitates the use of the THRU option on the card more often than is possible in many other similar cases.

- Primary Element Specification

The same element can appear as the primary ID on more than one CNGRNT card, but an element listed as a primary ID on one CNGRNT card cannot be listed as a secondary ID on <u>another</u> CNGRNT card. However, if a primary ID is also listed as a secondary ID on the <u>same</u> card, then such secondary IDs are ignored.

- Secondary Element Specification

The same secondary ID cannot be listed as congruent to two or more different primary IDs.

- Redundant Specifications

Redundant specifications on CNGRNT cards are ignored.

FACTORS AFFECTING CONGRUENT FEATURE EFFICIENCY

As indicated earlier, the use of the congruent feature results in increased computational efficiency. The degree of efficiency obtained depends on the following factors some of which can be influenced by the user input specifications:

- Number of Congruent Elements

Clearly, the larger the number of elements in a congruent set and the larger the number of sets, the higher the savings in CPU time.

- Type of Elements Specified as Congruent

Larger savings in CPU time are obtained for certain element types than for other element types. Thus, for instance, declaring two IHEX3 elements as congruent will result in more savings than declaring two IHEX1 elements as congruent.

- Type of Analysis

For a specified congruent set, larger savings are obtained in dynamic analysis than in static analysis since, in the former, mass and/or damping matrices need to be computed in addition to stiffness matrices.

- Numbering of Grid Points of the Congruent Elements

Processing is slightly more efficient if the relative order of the numbering of the grid points of the congruent elements is the same. Thus, for instance, two congruent quadrilateral plate elements are processed more efficiently if their grid points are numbered 1-7-4-6 and 12-23-16-20, respectively, than if they were numbered 1-7-4-6 and 11-14-17-15, respectively. In the former case, the grid point numbers of the two congruent elements increase or decrease in the same order as we go around the elements. In the latter case, the grid point numbers of the two congruent elements increase or decrease in different orders as we go around the elements.

SOFTWARE DESIGN OF THE CONGRUENT FEATURE

The preliminary checking of the validity of the data on the CNGRNT bulk data cards is performed in subroutine IFS1P of the IFP module, but the detailed processing of these cards is done in subroutine EMGCNG of the EMG module. Besides checking for various errors in the CNGRNT data, the EMGCNG routine sets up a table of congruent element IDs in open core. This important table forms the basis for handling congruent elements subsequently in subroutines EMGPRO and EMGOUT of the EMG module. It is, therefore, useful to know the manner in which this table is set up. (The detailed manner in which congruent elements are handled in the EMG module can be ascertained from the source code and from Reference 3.)

The congruent element table consists of a pair of words for each element (primary or secondary) specified on a CNGRNT card. The first word of this pair contains the user-specified ID of the element. The second word of the pair indicates whether the element identified by the first word is the primary ID of that congruent set or is a secondary ID of that set. In the case of a secondary ID, the second word of the pair is a positive integer specifying the open core address of its primary ID. In the case of a primary ID, the second word of the pair is either zero or a negative integer. Initially, this word is set to zero in the case of all primary IDs. When the element matrices for the first element (which is also the lowest numbered element) in a congruent set are computed, the zero in the corresponding word is changed to the negated open core address of the element matrix (or dictionary) data.

The second word of any pair of words in the congruent element table thus contains very important information. If it is a positive integer, then it is a pointer to the primary ID of that congruent set. If it is zero, then the corresponding ID in the first word is the primary ID and the element matrices have not yet been computed for that set. If it is a negative integer, then the corresponding ID in the first word is the primary ID and the element matrices have been computed for that set and can be obtained from the open core address information represented by that negative integer. The table as set up by the EMGCNG routine is sorted on the element IDs in the first words of the word pairs. An example of a congruent element table is shown in Table 1.

The unique design of the congruent element table allows for a very efficient processing of the congruent data by the EMG module. It should be noted that the EMG module will never mix element matrices for different element types. The EMG module processes each element type one after another. When it completes the processing of an element type, the negated open core addresses in the congruent element table (if any) are replaced by zeroes. Thus, when the processing of the next element type starts, the congruent element table (if any) has no history or evidence of the processing of the previous element type. Note also that the design of the table permits the specification of non-existent element IDs in the CNGRNT data.

EXAMPLES OF CONGRUENT FEATURE USAGE

There are 82 demonstration problems in Level 17.5 of NASTRAN. The congruent feature is employed in fifteen (15) of these problems. A comparison of the EMG module CPU times (on IBM S/360-95 computer) for these problems with and without the congruent feature is presented in Table 2. The savings resulting from the use of the congruent capability are quite apparent from this table. The most dramatic savings are obtained in NASTRAN Demonstration Problem Nos. 3-1-2 and 8-1-2 (UMF Problem ID Nos. 30120 and 80120, respectively) in which the EMG module CPU times are reduced by more than 99 percent.

SUMMARY

The congruent feature in NASTRAN is explained and the software design characteristics affecting its usage and the factors affecting its efficiency are discussed. The details pertaining to the software design of the capability are presented. Examples illustrating the usage of the feature are considered. The results of the paper clearly demonstrate the role of the congruent feature in increasing computational efficiencies and its applicability to large-size problems.

REFERENCES

1. Field, E. I., Herting, D. N., and Morgan, M. J., NASTRAN User's Guide, (Level 17.5), NASA Contractor Report 3146, June 1979, p. 14.3-3.

2. The NASTRAN User's Manual, (Level 17.5), NASA SP-222 (05), December 1978, p. 2.4-36a.

3. The NASTRAN Programmer's Manual, (Level 17.0), NASA SP-223 (04), December 1977, Section 4.124.

APPENDIX

Input Data Card CNGRNT   Identical Elements Indicator

Description: Designates secondary element(s) identical to a primary element.

Format and Example:

1	2	3	4	5	6	7	8	9	10
CNGRNT	PRID	SECID1	SECID2	SECID3	SECID4	SECID5	SECID6	SECID7	abc
CNGRNT	11	2	17	34	35	36			

+bc	SECID8	SECID9		-etc.-					

Alternate Form

CNGRNT	PRID	SECID1	"THRU"	SECID2					
CNGRNT	7	10	THRU	55					

Field	Contents
PRID	Identification number of the primary element (not necessarily the lowest number)
SECIDi	Identification number(s) of secondary element(s) whose matrices will be identical (or congruent) to those of the primary element.

Remarks:

1. Orientation, geometry, etc. must be truly identical such that the same stiffness, mass and damping matrices are generated in the global coordinate system.
2. This feature is automatically used by the INPUT module.
3. The CNGRNT feature cannot be used when an AXIC card is present in the bulk data deck.
4. An element that has been listed as a primary ID on a CNGRNT card cannot be listed as a secondary ID on another CNGRNT card. However, if the element is listed as a secondary ID on the same card, then such secondary IDs are ignored.
5. The same secondary IDs cannot be listed as congruent to two or more different primary IDs.
6. Redundant specifications on CNGRNT cards are ignored.
7. The stiffness, mass and damping matrices are actually calculated for the lowest numbered element in the congruent set (even though this element may not be the primary ID).

TABLE 1. - EXAMPLE OF A CONGRUENT ELEMENT TABLE

Open Core Location	Table Column 1	Table Column 2
Z (53)	1	54
Z (54)	3	0
Z (55)	7	59
Z (56)	12	54
Z (57)	15	59
Z (58)	18	54
Z (59)	36	0
Z (60)	40	59
Z (61)	69	54

Note: The above table represents the congruent element table as initially set up by EMGCNG routine resulting from the processing of two CNGRNT bulk data cards--one with a primary ID of 3 and secondary IDs of 1, 12, 18 and 69 and the other with a primary ID of 36 and secondary IDs of 7, 15 and 40.

TABLE 2. - EXAMPLES OF CONGRUENT FEATURE USAGE IN LEVEL 17.5 NASTRAN DEMONSTRATION PROBLEMS

Example No.	Demonstration Problem No.	UMF Problem ID No.	Congruent Element Data			EMG Module CPU Times (sec.)*		Saving in EMG Module CPU Time Obtained by Using the Congruent Feature (%) $\frac{(b) - (a)}{(b)} \times 100$
			Element Type	Number of Elements	Number of CNGRNT Sets	Using the Congruent Feature (a)	Without Using the Congruent Feature (b)	
1	1-3-1	10310	QDMEM	216	1	0.8	8.3	90.4
2	1-3-2	10320	QDMEM1	216	1	1.2	13.5	91.1
3	1-3-3	10330	QDMEM2	216	1	1.5	11.1	86.5
4	1-8-1	10810	HEXA1	40	1	0.1	3.5	97.1
5	1-9-1	10910	HEXA2	40	1	0.3	7.4	95.9
6	1-11-1	11110	QUAD1	50	1	0.2	7.7	97.4
7	1-13-1	11310	IHEX1	40	5	2.8	16.9	83.4
8	1-13-2	11320	IHEX2	2	1	2.7	4.5	40.0
9	3-1-1	30110	QUAD1	200	1	0.4	15.4	97.4
10	3-1-2	30120	QUAD1	800	1	0.8	130.5	99.4
11	5-1-1	50110	TRIA1	80	4	0.7	11.7	94.0
12	8-1-1	80110	QUAD1	100	1	0.4	5.8	93.1
13	8-1-2	80120	QUAD1	400	1	0.4	49.1	99.2
14	14-1-1	140110	QUAD2	10	5	1.7	2.3	26.1
15	15-1-1	150110	BAR	10	5	1.4	5.0	72.0
			QUAD2	20	5			

*All of the above problems were run on the IBM S/360-95 computer.