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GAP: THE IBM 704 GRID ANALYSIS PROGRAM

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GAP: THE IBM 704 GRID ANALYSIS PROGRAM

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DATE ISSUED

MAY 2 1960

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Oak Ridge, Tennessee
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UNION CARBIDE CORPORATION
for the
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ABSTRACT

GAP is an IBM 704 program for analyzing simply-supported rectangular beam grillages in which the beams intersect at right angles. The grillage need not be symmetrical and may have both uniformly distributed and concentrated loads. Also, the individual beams may have arbitrary cross sections. Strain energy methods are used to determine the bending, shearing, and torsional effects in a given grid structure. Deflections and moments can be found directly by the program, and series coefficients are provided for additional computation.

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NOMENCLATURE¹

A	cross sectional area of a beam
$a_{mn}, m, n=1, 2, \dots$	series coefficients
E	modulus of elasticity
G	shear modulus of the material
g	the number of beams perpendicular to the y-axis of the grid
h	the number of beams perpendicular to the x-axis of the grid
I	moment of inertia of the cross section with respect to the neutral axis (axis of rotation)
J	a torsional factor dependent on the geometry and dimensions of the cross section (polar moment of inertia if the cross section is a circle) ²
L_I	the common length of the beams perpendicular to the x-axis
L_J	the common length of the beams perpendicular to the y-axis
P	a concentrated load (positive downward)
q	a uniform load per unit length (positive downward)
$s = \frac{cEI}{2GA}$	a shearing constant
$t = \frac{GJ}{EI}$	a torsional constant

¹Any consistent set of units may be used.

²This corresponds to K given by R. J. Roark, Formulas for Stress and Strain, 3rd Ed., pp 170-179, McGraw-Hill, New York, 1954.

w deflection (positive downward)
 x_i x coordinate of i th beam perpendicular to x-axis
 y_j y coordinate of j th beam perpendicular to y-axis
 α cross sectional shearing constant³

Subscripts

x_i, i denotes property associated with the i th beam
perpendicular to the x-axis
 y_j, j denotes property associated with the j th beam
perpendicular to the y-axis

³A discussion of this is found in S. Timoshenko, Strength of Materials, Part I, 3rd Ed., pp 113-125, D. Van Nostrand Company, Inc., New York, 1955.

1. INTRODUCTION

The grid analysis program, GAP, described herein, is a SAP (SHARE Assembly Program) assembled program that was written for use in analyzing simply-supported rectangular beam grillages in which the beams intersect at right angles. The individual members may have arbitrary cross sections. The code was specifically written for the 8192-word core-memory IBM 704 at the Oak Ridge Gaseous Diffusion Plant (K-25) in Oak Ridge, Tennessee.

A thorough description of the analytical method for which GAP was compiled is given in a separate report.¹ In order to analyze a structure, the coordinate system must be set up as shown in Fig. 1; the notation is that of the grid analysis report. In the analysis, strain energy methods are used, and the deflection of the grid is given by

$$w = \sum_m \sum_n a_{mn} \sin \frac{m\pi x}{L_J} \sin \frac{n\pi y}{L_I} .$$

Bending, shearing, and torsional effects may be considered in investigating a given grid structure. If the grid is deflected symmetrically about the center lines, only the odd numbered values for m and n should be used; both even and odd numbers must be used if the deflection is nonsymmetrical. The program is designed primarily for evaluating the coefficients, a_{mn} .

The author is indebted to C. L. Allen whose advice was often sought on programming technique and procedure.

¹F. J. Stanek and F. J. Witt, Analysis of Simply Supported Rectangular Grids of Perpendicular Beams (to be published).

Fig. 1. Mathematical Model of a Simply-Supported Rectangular Grid of Perpendicular Beams

2. THE GAP CODES

Code for Symmetrical Grid Structures (Symmetric Code) - This code is used when it is known that the deflection is symmetrical about the center lines. With the cards in the card reader hopper the instruction to the operator is CLEAR and LOAD CARDS. With the exception of octal address 00143, the remaining core memory is used by the program.

Code for Nonsymmetrical Grid Structures (Nonsymmetric Code) - This code is a short, corrective program for the symmetric code and must be used if the deflection is not symmetrical about the center lines. It is not necessary to load the symmetric code again; thus, the usual procedure is first to analyze all of the symmetrical cases and, next, to load this code for analyzing nonsymmetrical cases. With the cards in the card reader hopper, the instruction to the operator is LOAD CARDS (do not clear the memory!). A unified non-symmetric code which can also be used to solve symmetrical grid structures may be made by removing the first five cards (the octal loader) and the last card (the transfer card) from the deck and inserting the remaining cards into the symmetric code deck immediately preceding the transfer card. This procedure, however, restricts the number of non-zero odd numbered coefficients for the symmetrical case to nine or less. The core memory is used by the program.

3. SUBROUTINES

The following subroutines, together with their octal locations, are used:

NO SMQA (297) and GL DPAI (110)	: 00145
NY OUT 3	: 01035

NY INP1 (206) : 01665
UA S + C1 (013) : 02761

The numbers in parentheses refer to the SHARE listings.

In octal location 06644 is a subroutine written to be used in conjunction with UA S + C1. This subroutine compares a floating point number in the accumulator with 10^{-4} . If the number is less than 10^{-4} , it is replaced by zero. By this procedure, underflow in deriving the matrix elements and solving the matrix equations is somewhat circumvented. The number 10^{-4} is in octal location 06657. The effect of this subroutine can be changed (or nullified) by replacing 10^{-4} by another floating point number (or 0).

In octal location 06716 is a routine which compares the first element of the bending matrix and of the bending and shearing matrix to all the other elements in the matrix, respectively. If the ratio of any element to the first element is less than 10^{-4} , the element in question is replaced by 0. This procedure helps to prevent overflow and underflow in solving the matrix equations. The number 10^{-4} is in location 06756. The effect of this routine can also be changed as indicated above, or the subroutine may be deleted by placing the octal word, 002000005234, in octal location 05232.

The two routines described above were found necessary for the analysis of homogeneous grids.⁵ Their effect is probably negligible in most other cases.

⁵Ibid.

4. CODED STOPS

Certain stops other than those listed below may occur due to redundancy and error stops in subroutines. Incorrect input is the most frequent cause of such stops.

Listed below are the octal location (contents of the instruction counter), the words on which the code stops (contents of the storage register), and an explanation of each programmed stop. To proceed with the analysis after each stop, the START button should be pressed. Any stop may be deleted by making the appropriate binary correction card, that is, replacing HTR (0000) by TRA (0020) in the instruction part of the word.

- 00144 : 000000003056 - The program stops here after the code is loaded and before a new case is to be analyzed. The input should be in the card reader hopper before proceeding.
- 05236 : 000000005237 - Overflow and/or underflow has occurred in computing the matrices. Sometimes this does not affect the final results but such information should be noted.
- 05456 : 000000005457 - Sense switch 3 is on. Sense switch 3 may be turned off at this location as indicated in Section 5.
- 05572 : 000000000144 - Overflow or underflow has apparently occurred in solving the matrix equations. This may not be the case, however, as the MQ overflow light is quite often left on by one of the subroutines even though no evidence of overflow or underflow is present in the output.

05612 : 000000005751 - A numerically singular matrix has been generated by the program. Sense switch 5 may be turned on to secure the system of equations.

06064 : 000000006111 - In computing the deflections and moments along a beam, the y-coordinate of a non-existent beam has been given.

06136 : 000000006111 - In computing the deflections and moments along a beam, the x-coordinate of a non-existent beam has been given.

5. SENSE SWITCHES, INPUT AND OUTPUT

All input is by subroutine NY INP1; hence, all input must conform to the restrictions of this subroutine. In the description of the sense switches below, a DEC card is referred to as if it could contain all the numbers of a particular category. This is not necessary, but the first number of each category must be the first number on a DEC card. A familiarity with the discussion of normalized grids⁶ may aid in setting up the input for studying grid parameters.

All input numbers except those designated by DI are decimal floating point numbers. A designation of DI means the number is a decimal integer with no decimal point and exponent.

The output is on logical tape 9 by subroutine NY OUT 3 and an end-of-file instruction is inserted after each completed case or study. If several cases and studies are run, it is a good practice

⁶Ibid.

to place an END OF TAPE⁷ on the tape when the job is completed. The output magnetic tape should be printed under Program Control with Automatic Overflow on. The best paper size for most cases is 11" x 8 1/2". The regular sequence of output is such that data corresponding to bending effects alone are given first; then the data for bending and torsional effects combined, followed by bending, shearing and torsional effects combined, and lastly, bending and shearing effects combined are given. For the symmetrical case, the maximum deflection and moment are listed, while for the nonsymmetrical case the maximum deflection and moment of the grillage nearest the center are given. Additional output that may be obtained is discussed below.

All sense switches are defined and great care should be exercised in their use. Switch 5 is the only one independent of the input. The order of precedence of the sense switches with regard to input is as follows: 2,6,3,4. A sense switch is said to be on if it is in the down position and off if it is in the up position.

Sense Switch 1 - This switch must be on for NY INP1 card input and GL DPA1 double precision routine. GL DPA1 is used only in solving the matrix equations; however, overflow or underflow is not as likely to occur in solving the matrix equations if single precision is used. Single precision solutions may be obtained by turning this switch off as soon as the last initial-input card is read. They may also be obtained by placing the octal word, 000000005234, in octal location 06755. This procedure stops the program and allows switch 1 to be turned off (to proceed, press START). Switch 1, however, must be on when additional card input is to be read. In practice this is seldom a problem for consideration.

⁷This is a local one card program.

Sense Switch 2 - Switch 2 is the main input control. If it is off the cards, if required, must follow in the sequence listed below. Each category is called for separately.

<u>Type of Card</u>	<u>Category</u>	<u>Description of Input</u>
BCD	ID Card	Identification, columns 13 to 72 (one card only)
DEC	IN Card	$r, g, L_J, h, L_I, \sigma, \theta$ (These are defined below.)
DEC	YJ Card	The y coordinates, y_1, y_2 , etc. of beams perpendicular to y- axis
DEC	EIJ Card	$(EI)_{y1}, (EI)_{y2}$, etc. for beams perpendicular to y-axis
DEC	QJ Card	The uniform loads per unit length, q_{y1}, q_{y2} , etc. for beams perpen- dicular to y-axis
DEC	TJ Card	The torsional constants, t_{y1}, t_{y2} , etc. for beams perpendicular to y-axis
DEC	SJ Card	The shearing constants, s_{y1}, s_{y2} , etc. for beams perpendicular to y-axis
DEC	XI Card	The x coordinates, x_1, x_2 , etc. of beams perpendicular to x-axis
DEC	EII Card	$(EI)_{x1}, (EI)_{x2}$, etc. for beams perpendicular to x-axis
DEC	QI Card	The uniform loads per unit length, q_{x1}, q_{x2} , etc. for beams perpen- dicular to x-axis
DEC	TI Card	The torsional constants, t_{x1}, t_{x2} , etc. for beams perpendicular to x-axis
DEC	SI Card	The shearing constants, s_{x1}, s_{x2} , etc. for beams perpendicular to x-axis
DEC	CL Card	There are θ such cards in all and on each card is P_k, x_{ik}, y_{jk} where (x_{ik}, y_{jk}) is the location of concen- trated load P_k . These cards are called for individually and the numbers given are not saved.

If all the beams in a given direction have the same properties, then switch 2 may be turned on and the above input altered as follows: EIJ, QJ, TJ, and SJ cards are replaced by a decimal card containing the common values $(EI)_y$, q_y , t_y , and s_y in this order. EII, QI, TI, and SI cards are replaced by a decimal card containing the common values $(EI)_x$, q_x , t_x , and s_x in this order.

The numbers on the IN card are defined as follows:

- γ : γ^2 is the number of coefficients desired. The maximum γ is five. DI
- g : The number of beams perpendicular to y-axis (maximum is 90). DI
- L_J : The common length of the beams perpendicular to the y-axis.
- h : The number of beams perpendicular to x-axis (the maximum is 90). DI
- L_I : The common length of the beams perpendicular to the x-axis.
- σ : If σ is 0, only the bending input must be available (no TJ, SJ, TI, and SI cards). If σ is 1, bending and torsional input must be available (no SJ and SI cards). If σ is -1, bending and shearing input must be available (no TJ or TI cards). If σ is 2, total input sequence must be available. DI
- θ : The number of concentrated loads. DI

Sense Switch 3 - A parametric study in γ is not desired if this switch is off. If switch 3 is on, a parametric study of γ is made. A DEC card with a value for γ (defined above) is read and the problem analyzed for this value. The study is terminated when a zero value for γ is read and the code stops at octal location 05456. If concentrated loads are part of the input, CL cards must follow each non-zero DEC card containing a value for γ .

Sense Switch 4 - No parametric study on shearing and torsional effects is desired if this switch is off. If switch 4 is on, a parametric study including shearing and torsional effects is

desired (depending on σ).

The card sequence is as follows for each parameter study.

<u>Type of Card</u>	<u>Category</u>	<u>Description of Input</u>
DEC	Instruction Card	ξ , where ξ is 2 if torsional and shear changes are available, 1 for torsional changes only, 0 for shear changes only and -1 if the study is to be terminated. σ is not changed in the program. DI
DEC	TJ Card	These cards are defined above and must be available if a parametric study in torsional effects is desired.
DEC	TI Card	
DEC	SJ Card	These cards are defined above and must be available if a parametric study in shearing effects is desired.
DEC	SI Card	

Sense switch 2 does not alter this sequence.

Sense Switch 5 - The matrices and vector are not desired if switch 5 is off. If switch 5 is on, all matrices and the vector are written on logical tape 9. Matrices are written by rows with a maximum of 9 vector elements per line.

Sense Switch 6 - No deflection and moment computations are desired along a beam if switch 6 is off. If switch 6 is on, deflections and moments at equal intervals along one or more beams are desired.

A sequence of DEC cards are read, each card containing the following:

γ : $\begin{cases} 1 & \text{if } x_i, \Delta y \text{ is given } (\Delta y \text{ is increment in } y). \text{ DI} \\ 0 & \text{if } \Delta x, y_j \text{ is given } (\Delta x \text{ is increment in } x). \text{ DI} \end{cases}$

x_i (or Δx)

Δy (or y_j)

ρ : $\begin{cases} 0 & \text{if the calculation is completed. DI} \\ 1 & \text{if another such card is to follow. DI} \end{cases}$

The deflections and moments are calculated using the last set of coefficients listed in the regular output. If a complete analysis is being run, deflections and moments due to bending, shear and torsion may be computed by placing the octal word, 002000005436 in octal address 05405. If this is done, however, no output relating to bending and shear is given.

6. EXAMPLE

The symmetrical grid of like beams in Fig. 2 which, in addition to a uniform loading of 10.5 lb/in., has concentrated loads of 50 lb located at points A, B, C, and D is to be analyzed. Deflections and moments at intervals of three inches along all the beams are desired. The torsional constant is found to be 0.001 and is deemed to be negligible for the analysis. Additional input is as follows:

$$EI = 4.92 \times 10^{10}$$

$$s = 7.73$$

It is assumed that four coefficients will give an accurate approximation; a close inspection shows that singular matrices are generated for the analysis using nine coefficients.

The following input cards should be key-punched.

Columns

8 12

BCD J. D., PROBLEM NO. . . .

DEC 2, 4, 36., 2, 75., -1, 4.

DEC 15., 30., 45., 60.

Fig. 2

```

8      12
DEC    4.92E10,10.5,7.73
DEC    12.,24.
DEC    4.92E10,10.5,7.73
DEC    50.,12.,45.
DEC    50.,12.,30.
DEC    50.,24.,45.
DEC    50.,24.,30.      (End of regular input)
DEC    1,12.,3.,1      }
DEC    0,3.,15.,1      }   Cards for calculating
DEC    0,3.,30.,0      }   deflections and moments
                           }   along beams

```

The code is to be operated with sense switches 1, 2, and 6 on. With the input following the symmetric code and the deck placed in the card reader hopper the operations are listed below.

- a. CLEAR and LOAD CARDS.
- b. Code stops on HTR at 00144. START.
- c. Grid is analyzed for 4 coefficients and output is on logical tape 9. A card reader stop will occur; if so, press START on card reader.⁸
- d. Code stops on HTR at 5572. START.
- e. Code stops at 00144.

About 15 seconds are required to analyze the grid and record the results on logical tape 9. The coefficients are listed below.

Analysis for bending only:

$$\begin{array}{ll}
 a_{11} = .12954 \times 10^{-4}, & a_{31} = .44284 \times 10^{-6} \\
 a_{13} = .23737 \times 10^{-7}, & a_{33} = .56035 \times 10^{-8}
 \end{array}$$

⁸ This stop can be avoided by placing two cards following the last input card.

Analysis for bending and shear:

$$a_{11} = .14400 \times 10^{-4}$$

$$a_{13} = .48889 \times 10^{-6}$$

$$a_{31} = .54135 \times 10^{-6}$$

$$a_{33} = .11541 \times 10^{-7}$$

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