Interactive Cross-Section Design Using PATRAN and MSC/NASTRAN

Keith J. Meyer

PDA Engineering
Costa Mesa, California

Abstract

The cross-section properties required for detailed beam analysis, including torsion and warping constants, shear stiffness factors, and optimal stress recovery points, can be difficult to calculate for even the simplest shapes. Complicated multi-cell, mixed open-closed sections are often used by the automotive and aerospace industries and the calculation difficulties overwhelm manual techniques. P/SECTION is an interactive and graphical program in the PATRAN system that accepts any shape defined by the parametric lines in PATRAN, automatically diagnoses the topological structure (cell boundaries, sectorial coordinates, etc.) and allows interactive review and remedial action (overlap identification, placement of spot welds, etc.). All cross-sectional properties required for beam analysis are then calculated and stored in an MSC/NASTRAN PBAR or PBEAM format, readily available for use in an MSC/NASTRAN structural analysis. The interactive, graphical abilities of P/SECTION enhance the advanced analysis and design features of MSC/NASTRAN for frame stiffened structures.

Introduction

The analysis of beams is often the starting point in the engineer's introduction to mechanics, and will remain an invaluable tool for later projects. The theory can also grow with the need, starting from elementary theory in which only normal stresses are desired and continuing to advanced theory for torsional and warping stresses. Unfortunately, the advantages of the theory are often weighed against the need to calculate the geometrical properties of the cross-section, which are known as section properties. The computational difficulties associated with these properties are roughly proportional to the level of the theory, i.e. only the area and moments of inertia are required for elementary calculations while advanced calculations require shear center, torsional constant, and warping constant to name a few. To evaluate the properties of even a moderately complicated structure can be a time-consuming and error-prone task.

The calculation of section properties in PATRAN is a newly developed capability in the module P/SECTION. The properties include not only the first order properties such as area, centroids, and moments of inertia but also properties developed from the sectorial coordinate including the shear center, and warping constant. The program is completely integrated with the geometric modeling capabilities of PATRAN, enabling the description of general curvilinear shapes to describe the cross-sectional geometry. The properties can later be assigned to a template for a MSC/NASTRAN BAR and BEAM element, and associated with elements in PATRAN for use in the analysis.

Beam Analysis With MSC/NASTRAN

MSC/NASTRAN has two elements in their library for beam analysis, named BAR and BEAM. The BAR element proceeds from elementary beam theory, and requires computation of the area, centroid, moments of inertia, and torsional constant. The BEAM element is the more advanced element, and requires all the properties for the BAR element and, in addition, will accept shear stiffness factors and offsets defining the shear center. In addition, the BEAM element can include a seventh degree of freedom to model the effects of warping.

The use of cross-sectional properties in the development of the beam stiffness proceeds from an assumption regarding the compatibility relations. This assumption of Navier, that plane sections remain plane, enables the analysis to be reduced from three to two dimensions. From this elementary theory, the calculation of extension and flexural behavior of beams in a general finite element program can be calculated by a variety of means. The properties required are the area, centroid, and moments of inertia of the cross-section.

A further assumption allows the twisting behavior of beams to be analyzed. This assumes that the rate of rotation of the beam is linearly proportional to the applied torque, and is known as St. Venant theory. The coefficient calculated in accord with this theory, called the torsion constant, can be seen to be proportional to the resistance of the cross section to twist. It is readily noted that this resistance greatly increases for a closed section, as opposed to an open cross section. Consider the case of a tube, with and without a slit through the thickness. Regardless of the existence of this slit, i.e. regardless of whether the cross section is open or closed, the areal properties (area, centroid, moment of inertia) remain unchanged. However, the resistance to twisting increases dramatically for the closed section. Thus, it is important to uniquely identify the cells of the cross section, i.e. the closed regions.

The Navier and St. Venant assumptions are all that are required for an elementary beam stiffness formulation, such as BAR. This element is remarkably robust and versatile, and should be used whenever the situation permits. However, increasingly with the complex shapes used in the automotive and aerospace industries, the engineer is forced to question the simplifying assumptions, and either use an advanced beam element or proceed to the expense of a solid element formulation.

Once the assumption of planar sections is relaxed, warping of the cross section is possible. As with torsion, the warping constant is greatly affected by the cellular makeup of the cross section. An additional complication arises in the calculation of the cross sectional properties associated with warping which must use the sectorial coordinate system in the calculation. This coordinate system is related to the swept out area by a sector moving from the system origin (usually a free end) with its center at the centroid or shear center. Using first the centroid, the coordinates of the shear center can be calculated. Then using the shear center, the warping constant can be found. The warping constant is analogous to the torsion constant, as it is proportional to the ability of the cross section to resist warping. Once these properties are calculated, they must be input on the PBEAM card with care taken to distinguish the shear center from the centroid. In addition, if warping is considered, an additional degree of freedom must be associated with each end of the beam along with appropriate restraint conditions. BEAM properties can be input for various stations along the length of the beam.

P/SECTION Module Capabilities

P/SECTION is a new PATRAN system module for the calculation and formatting of section properties for use in finite element packages. It is intended to be used in conjunction with the modeling features of PATRAN and thus uses the PATRAN database to transfer information to and from the module, as well as between the various functions of the module. P/SECTION will accept any assemblage of parametric cubic lines in the x-y plane for analysis. The parametric cubic line construction allows completely general description of the cross section. These lines are assembled into a named component, and stored on the PATRAN database. P/SECTION uses this same database to recover the construction geometry of interest and display it in a graphical window. The screen format of P/SECTION is depicted in Figure 1. At this point, the user will also be presented with a spreadsheet-type window displaying the data associated with each line. The only mandatory quantity is the associated thickness. Note that the thickness need not be constant, but can vary as a parametric cubic itself. Optional data include information for use in width/thickness ratios. This option uses either standard AISI formulae, or user-defined values to check the critical ratios in each straight, stiffened segment of the cross section, and delete material from the center of the segment if the ratio is exceeded. "Stiffened" segments are automatically identified as regions with "hard corners" at both ends, where a hard corner is defined by the included angle between segments (the angle definition can be defined by the user). Another optional datum is the density, for use in the calculation of mass (or weight) per unit length of the beam. A final datum is the Young's modulus, for use in column stiffness.

When all the mandatory data is entered, and the optional data as required, the program can then enter the "Verify" option of the program. This program finds the connectivity of the cross-section, and verifies that the cross-section is a completely joined structure (A disjoint structure can be analyzed, but only for the beam properties that do not depend on cell structure, and sectorial coordinates.). The program will then continue to find the type of structure being analyzed, such as open section, closed section, or closed section with open appendages. The appearance of the screen upon completion of this option is depicted in Figure 2 for a typical automotive section. For a closed section, a unique identifier will be placed at the centroid of all cells for graphical verification by the user. Once the section is identified, the integration order for use in the sectorial coordinates is determined.

At this time, control is returned to the user, and the "Analyze" option of P/SECTION is made available. The analysis section is the main processing module of P/SECTION and its output is largely dictated by the results of the "Verify" option. A procedure to analyze the section for shear factors is available, and the user will be prompted for this action.

Then the "Review" and "Store" options become available. The user is prompted to review either a short or long form of the properties. After review, the user may then pick the store option upon which the menu of target formats is made available. The MSC/NASTRAN formats defined by PBAR and PBEAM are available, as well as a generic PATRAN format. Upon selection, the properties will be written in the desired format to a file. An example of a typical section property file is given in Figure 3. The user can then associate the properties on this file to elements using the PATRAN PFEG command.

The Design Scenario

The procedure from the conceptual design through model verification is depicted in Figure 4. The beam model (or any general model containing a mixture of beam elements and other types of elements) can be geometrically modelled in PATRAN as line elements with one node at each end of the beam. At the same time, the details of the cross-section can be modelled in PATRAN and stored as a named component. P/SECTION can then be invoked, and the geometrical construction referenced through this named component. The user may at this time wish to use the interactive nature of P/SECTION to try to optimize design values by calculating section properties for a range of thicknesses for the elements of the cross-section, noting the design sensitivity. The user has various options during this procedure that may enable his later analysis, such as placing a local reference frame at the cross-section centroid. He will then select a format for storing the properties, and return to PATRAN. At this time, he may continue building his model, and associate the values stored by P/SECTION to his beam elements. Upon completion of the model, he will ask that the information can be collected in a PATRAN neutral file, and then shipped for translation to PATNAS which will form the MSC/NASTRAN bulk data file. Upon completion of the analysis, the results can then be ported back to PATRAN, via NASPAT, for use by the PATRAN image processing facilities. A future release of P/SECTION may allow detailed stress recovery within the cross-section based on these results, as well as graphical verification of the stress distribution on the cross-section.

Summary

The P/SECTION module of the PATRAN system is designed to automate a difficult and error-prone task that is necessary to the analysis of advanced frame structures. The calculation of the complete spectrum of beam properties, in a completely automated procedure with graphical feedback and the possibility of manual overrides, should greatly help the engineer in the preparation of analyses for MSC/NASTRAN. Coupled with the close connection to the general modelling features of PATRAN and the interactive procedures for associating these properties with beam elements in the general structure model, and the established interface programs between PATRAN and MSC/NASTRAN, the capability should prove invaluable to the engineer/analyst.

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References

1. Oden, J. T. and Ripperger, E. A., *Mechanics of Elastic Structures*, McGraw Hill Book Company, New York, New York, 1981.

2. Kollbrunner, C. F. and Basler, K., *Torsion in Structures-An Engineering Approach,* Springer-Verlag, Berlin, 1969.

3. Yoo, C.H. and Acra, S.V., "Cross-Sectional Properties of Thin-Walled Multi-Cellular Sections", *Computers and Structures,* Vol. 22, No.1, pp. 53-61, 1986.

4. MSC/NASTRAN User's Manual, The MacNeal-Schwendler Corporation, Los Angeles, California., 1985.

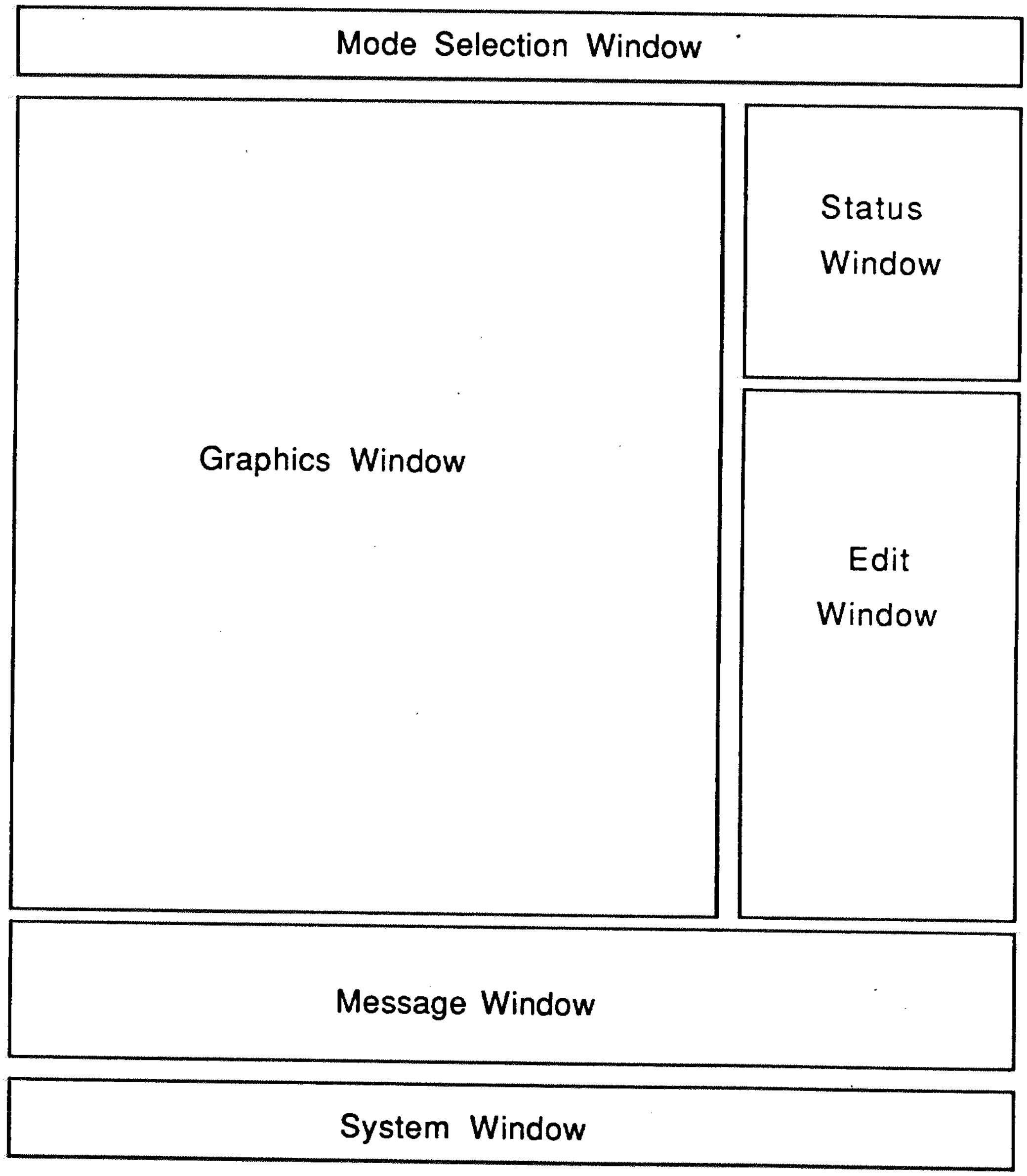

Figure 1. Schematic of P/SECTION Screen Design

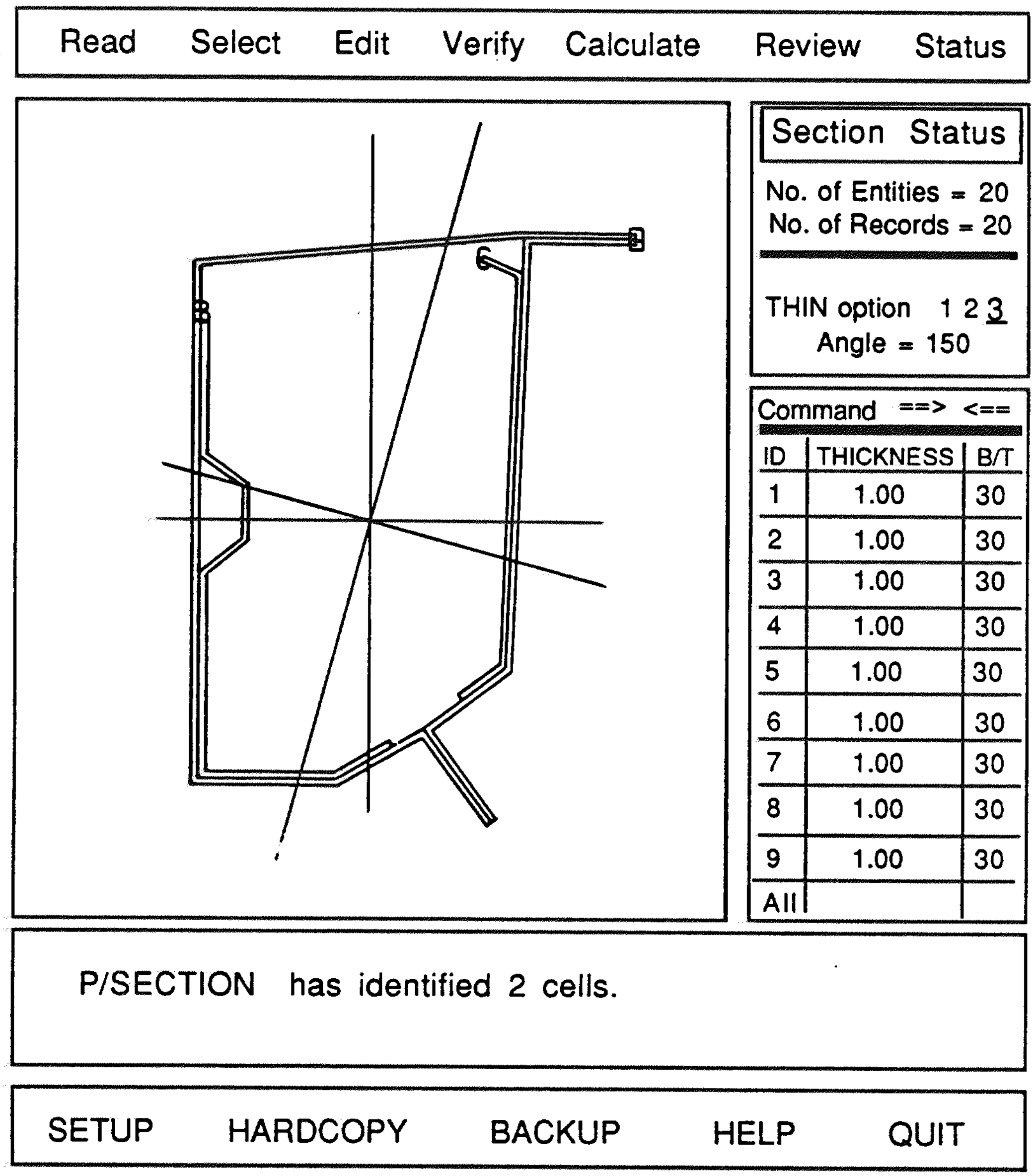

Figure 2. Typical Automotive P/SECTION analysis

*** THIS IS A NASTRAN BAR ELEMENT RECORD ***

CREATION DATE: 14-DEC-87 13:23:18

FORMAT:	NAME,	A,	IZZ,	IYY,	J
	NSM,	,	CY,	CZ,	DY
	DZ,	EY,	EZ,	FY,	FZ
	KY,	KZ,	IYZ		

TRIAL SECTION	0.48750E-01	0.23397E-01	0.30289E-01	0.16250E-05,
0.00000E+00	0.00000E+00	-0.34571E-05	0.39339E-05	-0.32187E-05,
0.41723E-05	-0.16563E+01	-0.16562E+01	0.16562E+01	0.16563E+01,
0.57045E+00	0.31969E+00	-0.21431E-01		

*** THIS IS A NASTRAN BEAM ELEMENT RECORD ***

CREATION DATE: 14-DEC-87 13:23:37

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	NSIB,	CWA,	CWB,	MYA,	MZA
	MYB,	MZB,	NYA,	NZA,	NYB
	NZB				

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0.41723E-05	-0.16563E+01	-0.16562E+01	0.16562E+01	0.16563E+01,
0.57045E+00	0.31969E+00	0.00000E+00	0.00000E+00	0.00000E+00,
0.00000E+00	0.90657E-02	0.90657E-02	0.00000E+00	0.00000E+00,
0.00000E+00	0.00000E+00	-0.60797E-05	0.13113E-05	-0.60797E-05,
0.13113E-05				

*** THIS IS A PATRAN STANDARD RECORD ***

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	SR(Y1),	SR(X2),	SR(Y2),	SR(X3),	SR(Y3),
	SR(X4),	SR(Y4),	KX,	KY,	CW,
	XD,	YD,	BETAX,	BETAY	

TRIAL SECTION	0.48750E-01	0.23397E-01	0.30289E-01	-0.21431E-01,
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-0.78625E+00	0.28610E-05	0.78625E+00	-0.16562E+01	0.77625E+00,
0.16563E+01	-0.77625E+00	0.57045E+00	0.31969E+00	0.90657E-02,
0.16563E+01	0.78125E+00	-0.33125E+01	-0.15625E+01	

Figure 3. Typical Section Property Records Written by P/SECTION For Use in PATRAN

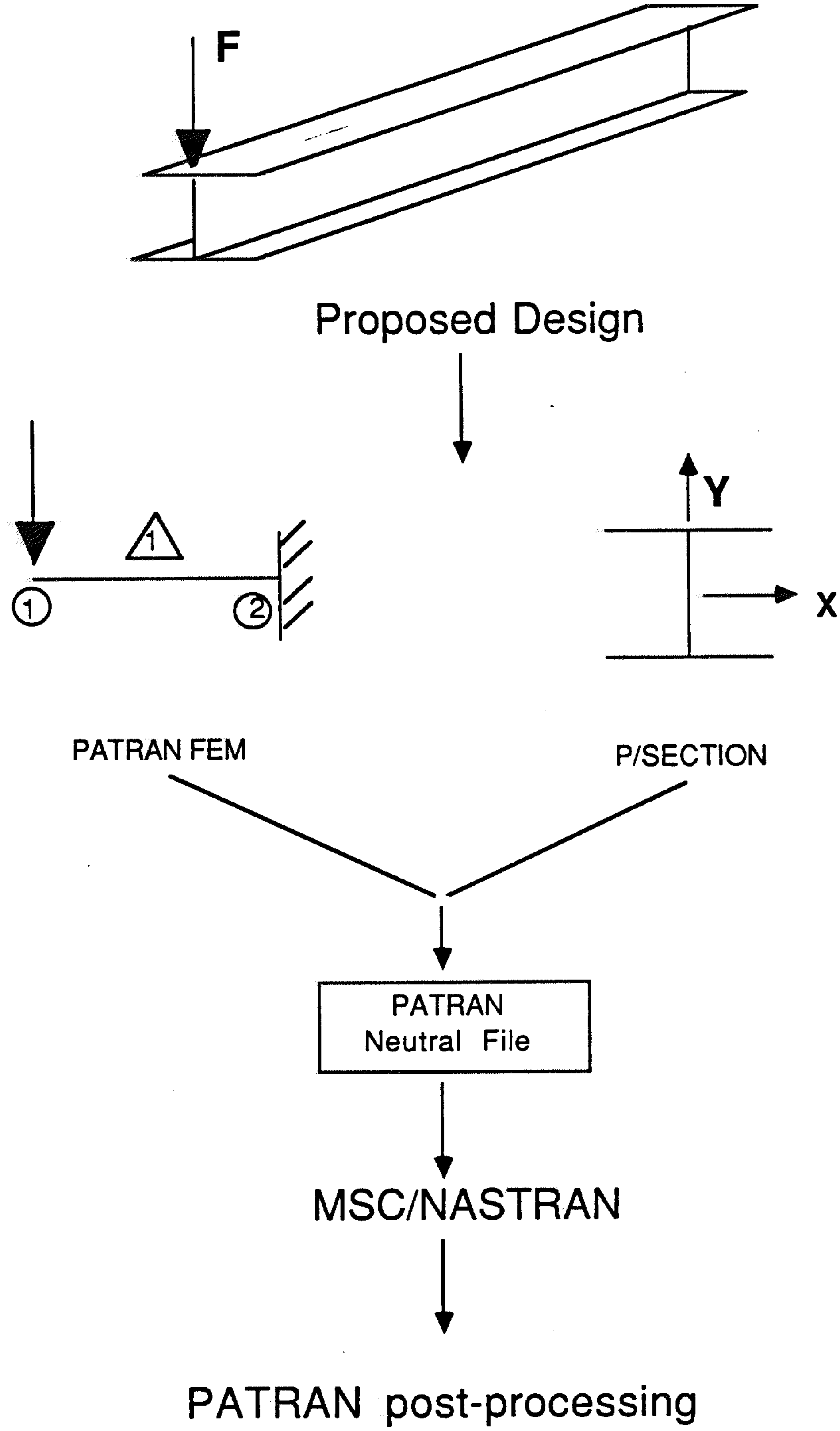

Figure 4. Schematic of the Analysis Process