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Structural Analysis System for Construction and Relining of Blast Furnaces

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Synopsis :
A Structural analysis system (KBSD System) for construction and relining of blast furnaces was established in order to save input data generating, judge speedily results of structural analysis and use effectively structural analysis program NASTRAN. Characteristics of this system are as follows: (1) The system is constituted by subsystems for generating input data, judging strength of framed structure member and deciding shell thickness of blast furnaces. (2) Structural analysis data is systematically stored in data-file. (3) Standard calculation sheet is make by computer output journal. (4) As this system is interactive, it is an efficient system with immediate correspondence. The system reduced about 70% of time conventionally required for structural analysis.

Structural Analysis System for Construction and Relining of Blast Furnaces*

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Characteristics of this system are as follows:

(1) The system is constituted by subsystems for generating input data, judging strength of framed structure member and deciding shell thickness of blast furnaces.

(2) Structural analysis data is systematically stored in data-file.

(3) Standard calculation sheet is made by computer output journal.

(4) As this system is interactive, it is an efficient system with immediate correspondence.

The system reduced about 70% of time conventionally required for structural analysis.

1 Introduction

Since the time of the relining of Mizushima No. 2 blast furnace (for third campaign) and No. 4 blast furnace (for second campaign), Kawasaki Steel has been pushing ahead with its blast-furnace relining independently rather than using outside contractors, covering such phases as design, manufacture and erection[1].

To improve techniques for future relining projects, a series of technical improvement programs have been under way and the authors have been engaged in the systematization of structural calculations for the construction and relining of blast furnaces.

Structural calculations for the construction and relining of blast furnaces mainly consist of a framed structure analysis using a composite model of the blast furnace proper, structural frames, crude gas main and dust catcher, and a stress analysis by the finite element method (FEM) using a shell model of the blast-furnace shell. These calculations are made by a general structural analysis program such as NASTRAN.

These structural calculations require immense calculation models. This has so far given a great load to the preparation and check on input data such as structure data and load data, and to the processing and evaluation of analysis results. Furthermore, there has been a problem that skilled analytical engineers fell short when work overlapped in the future construction and relining of blast furnaces.

This structural analysis system has been developed to make effective structural calculations and ensure safe and economical design in the future construction and relining of blast furnaces by solving the abovementioned problems.

This system has many features such as labor-saving in the preparation of input data, effective evaluation of analysis results and documentation of calculation results. Moreover, this system is an overall structural analysis system for the construction and relining of blast furnaces, in which each subsystem and NASTRAN are organically combined. This paper presents an outline of this structural analysis system called Kawasaki Steel Blast Furnace Structure Design System (KBSD system).

2 Design Flow of Blast Furnace Construction and Relining

Figure 1 shows the design flow of the blast furnace proper and structural frame. The design is broadly classified into the steps of planning, structural calcula-

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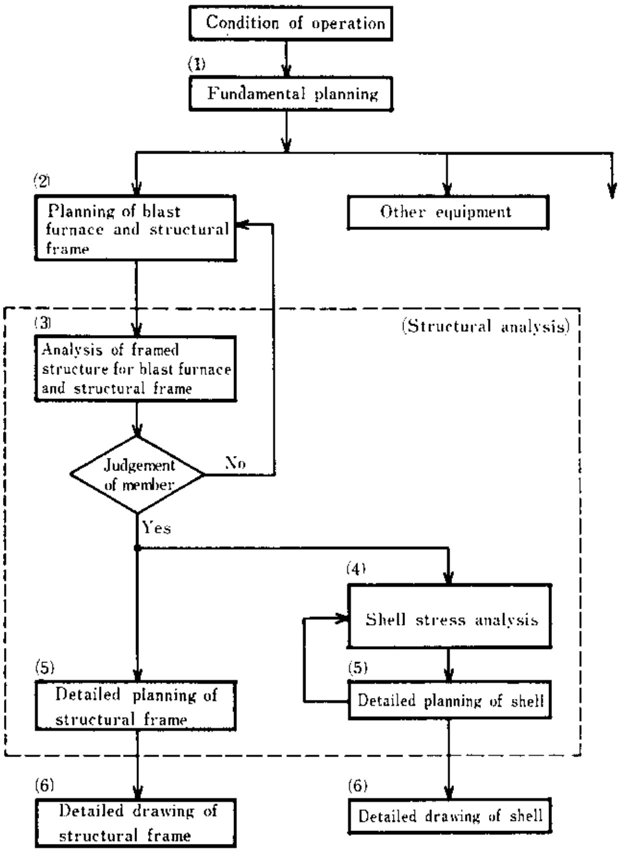

Fig. 1 Design flow of blast furnace

tion and preparation of drawings. Principal contents are as follows:

(1) In the fundamental planning, basic specifications such as furnace profile and furnace supporting method are determined based on the operational condition of the blast furnace.
(2) In the structural design, the cross section of members is determined in consideration of earthquake resistance, equipment arrangement, installation, weight, etc. based on the fundamental plan.
(3) In the framed structure analysis, framework drawings are prepared and then input data for structural analysis are prepared based on these drawings to make a structural analysis. In this analysis, judgment is passed on the strength of structural members; if there is any problem, the structural design is revised and a structural analysis is made again to ensure optimum design.
(4) The shell stress analysis by FEM is made to determine the shell thickness and construction based on results of the framed structure analysis.
(5) Detailed planning of structural frames is carried out when the strength of structural frame members has been checked after the framed structure analysis. Furthermore, detailed planning of the shell is carried out and at the same time, a shell stress analysis is made; if there is any problem in strength, the detailed plan is revised to ensure optimum design.
(6) Detail drawings are prepared based on the detailed plan.

In the design flow mentioned above, structural calculation is an important step for determining the basic construction of the blast furnace proper and structural frames, in which a great deal of data is processed; therefore, this step has so far required a greater load than any other design work.

3 Composition and Features of KBSD System

In the KBSD system, the blast furnace proper, which is a shell structure, and structural frames, crude gas main and dust-catcher supporting frames, which are framed structures, are regarded as composite models in making analyses to determine their constructions.

3.1 Composition of the System

Figure 2 shows the flow of the KBSD system. This system is divided in terms of function into the input data generation, framed structure analysis and processing of analysis results. This system is composed of subsystems; therefore, even if calculation methods and conditions are to be partially changed or improved in the future, only the subsystem in question can be modified without affecting the whole composition of the system.

Furthermore, the data transmission between each subsystem and NASTRAN is performed via data files and partial changes in data can be made simply by modifying data entered in data files.

In addition, final input data used for the structural analysis after the completion of the calculation are saved in data files for long. And, they can be used as information on blast furnace data bases at the company.

3.2 Function of Input Data generation

As shown in Fig. 2, the function of input data generating is mainly composed of a framed structure input data generating subsystem, a furnace body load calculation subsystem, and a structural frame load calculation subsystem. Each subsystem will be described in Chapter 4.

3.3 Function of Processing of Analysis Results

As shown in Fig. 2, the function of processing of analysis results is mainly composed of a subsystem for

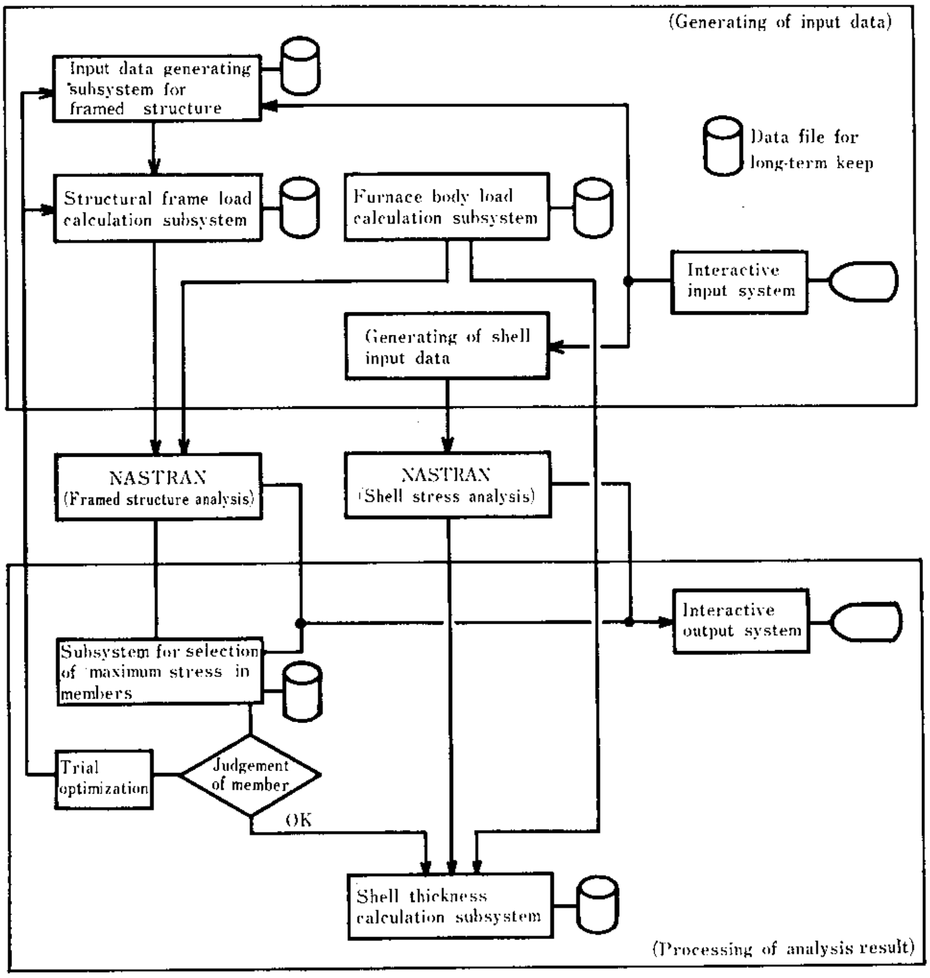

Fig. 2 Flow of KBSD system

selection of maximum stresses in members and a shell thickness calculation subsystem. Each subsystem will be described in Chapter 4.

3.4 Interactive Systems

An interactive input system is linked to the framed structure input data generating system and the input data generating part of NASTRAN. This system permits geometries of structures, load conditions and constraint conditions to be displayed on a graphic display and NASTRAN input data to be visually generated and checked. Furthermore, an interactive output system is linked to the NASTRAN and the subsystem for selection of maximum stresses in members. This system permits the check of results of NASTRAN analysis and those of selection of maximum stresses in structural frame members and the correction of sectional shapes of members. All operations of this system are controlled from terminal devices.

3.5 Documentation of Calculation Results

Output formats are prepared so that all calculation result lists and plotter drawings of each subsystem can be used as calculation documents in the as-outputted state. Output lists include ① lists of data on framed members of structural frames and plotter drawings of sectional shapes of members, ② lists of results of furnace body load calculations, furnace profile drawings and furnace body load distribution diagrams, ③ lists of calculated results of structural frame loads, ④ lists of selected maximum stresses in structural frame members, and ⑤ lists of calculated results of shell thickness.

4 Features of Each Subsystem

This chapter describes features of each subsystem.

4.1 Framed Structure Input Data generating Subsystem

(1) Function of input data generating
To generate input data efficiently, this subsystem has only the function necessary for a framed structure analysis by NASTRAN. Since basic structural analysis data by fixed formats are automatically converted into NASTRAN input data, this subsystem can be used even if the user is not well acquainted with NASTRAN.

(2) Function of calculation for cross sectional property of structural members[2)]
Structural frames contain members of cross sections as shown in **Fig. 3**. In this subsystem, if the cross section of each framed structure member is inputted, the geometric property of the member necessary for a framed structure analysis is calculated and NASTRAN input data are prepared. Moreover, the section modulus for calculating various stresses is calculated for the section of each member and the data are transmitted to the subsystem for selection of maximum stresses in members. **Figure 4** shows an example of calculated output of the geometric property of an H-shape member.

GEOMETRIC TABLE LIST			
GROUP NAME	H-TYPE	GEOMETRY NO.	80
GEOMETRIC SHAPE	TYPE-H	PROPERTY NO.	1

STRESS CALCULATION
POINT : ①~⑨

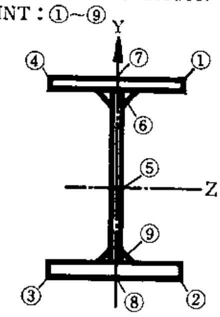

TABLE OF GEOMETRIC PROPERTY

NAME	NUMERICAL VALUE	DIMENSION
AS	45.600000E+01	CM ** 2
AWY	18.000000E+01	CM ** 2
AWZ	23.300000E+01	CM ** 2
AJ	16.400000E+02	CM ** 4
IY	28.600000E+03	CM ** 4
IZ	10.000000E+03	CM ** 4

AWY : Effective sectional area against y-direction shear
AWZ : Effective sectional area against z-direction shear
AJ : Effective polar moment of inertia of area
IY : Second moment of inertia around y-axis
IZ : Second moment of inertia around z-axis

Fig. 4 An example of geometric property list of framed member

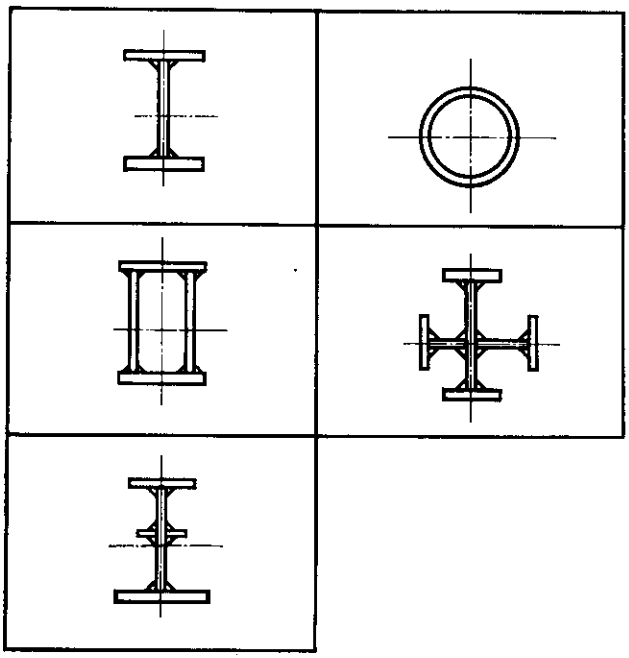

Fig. 3 Cross section of framed structure member

4.2 Furnace Body Load Calculation Subsystem

Figure 5 shows the flow of calculation of this subsystem. In this subsystem, the lateral pressure acting on the shell, vertical load and short-term load are calculated by inputting the furnace profile composed of the shell, staves and refractories, specific of each part, basic in-furnace blast pressure, characteristics of the stock, etc.

Figure 6 shows an example of plotter drawings of furnace profile and the distribution of lateral pressure to be transfered to shell. The average lateral pressure is outputted for each block of the furnace body.

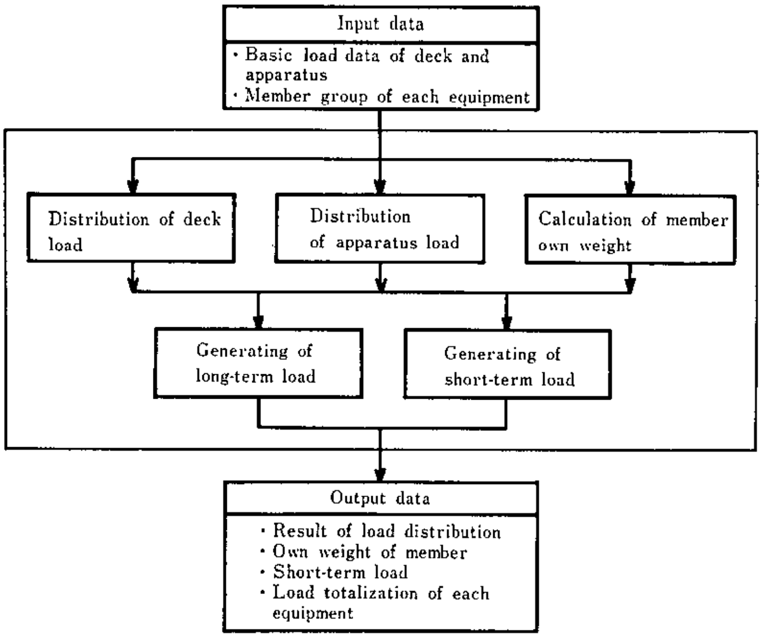

Fig. 5 Flow of furnace body load calculation subsystem

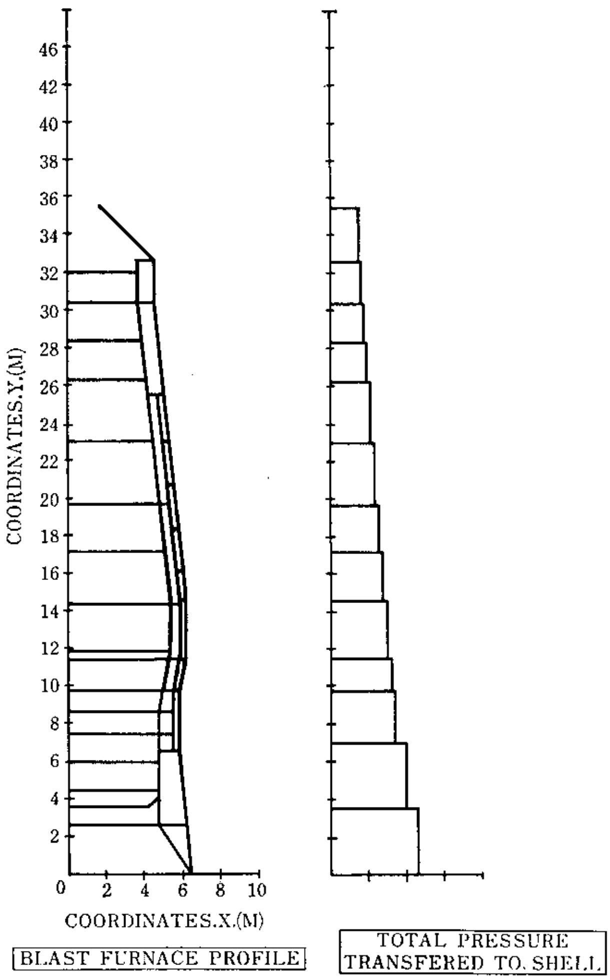

Fig. 6 An example of blast furnace profile and shell pressure drawing by plotter

4.3 Structural Frame Load Calculation Subsystem

Figure 7 shows the flow of calculation of this subsystem. In this subsystem, the distribution of floor live loads and apparatus loads to members and joints of framework, own weights of members, and short-term loads are calculated by inputting basic data on floor live loads of each deck of furnace structural frames and on apparatus loads, member groups of each piece of equipment, etc.

Calculated loads are summarized for each piece of equipment and calculated load lists are prepared. **Figure 8** shows an example of calculated structural frame load. This list contains own weight of the columns, girders and decks, live load, apparatus load and their total for each layer of beam.

4.4 Framed Structure Analysis

As shown in **Fig. 9**, the model for framed structure analysis is composed of beam elements of the blast furnace proper, structural frames, uptake, downcomer, dust catcher proper, dust-catcher supporting frames, etc.

Forces in sections of each member obtained by the framed structure analysis are transmitted to next subsystem for processing of analysis results through data files.

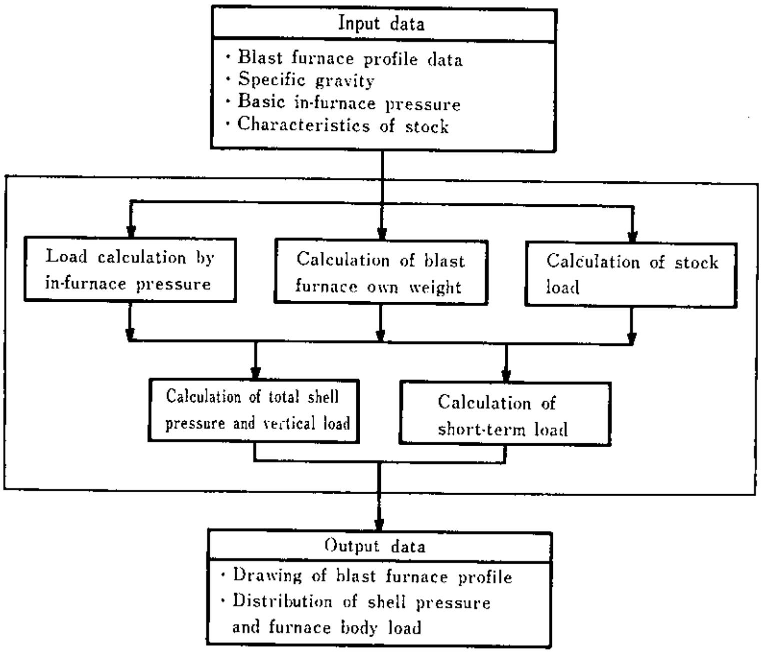

Fig. 7 Flow of structural frame load calculation subsystem

-G- NO.	-F- NO.	LONG-TERM LOAD: DEAD LOAD: COLUMN (TON)	GIRDER (TON)	FLOOR (TON)	CHARGE LOAD: LONG-TERM (FLOOR) (T/M**2) (TON)	SHORT-TERM (FLOOR) (T/M**2) (TON)	APPARATUS LOAD (TON)	SUBTOTAL VERTICAL (TON)	SUBTOTAL HORIZONTAL (TON)
		69.1	0.0	0.0	(0.0)	(0.0)	0.0	(+Z) 0.0	(+X) 0.0
					0.0	0.0	0.0	(-Z) 69.1	(-X) 0.0
							0.0		(+Y) 0.0
							0.0		(-Y) 0.0
0	0	0.0	21.3	184.7	(3.10)	(2.05)	0.0	(+Z) 0.0	(+X) 0.0
					1174.9	775.4	0.0	(-Z) 1380.9	(-X) 0.0
							0.0		(+Y) 0.0
							0.0		(-Y) 0.0
1	1	99.5	42.6	10.5	(0.10)	(0.08)	(-Z) 349.9	(+Z) 0.0	(+X) 0.0
					5.4	4.3	0.0	(-Z) 507.9	(-X) 0.0
							0.0		(+Y) 0.0
							0.0		(-Y) 0.0
1	2	0.0	0.0	19.7	(0.10)	(0.08)	0.0	(+Z) 0.0	(+X) 0.0
					15.6	12.5	0.0	(-Z) 35.3	(-X) 0.0
							0.0		(+Y) 0.0
							0.0		(-Y) 0.0

Fig. 8 An example of structural frame load calculation list

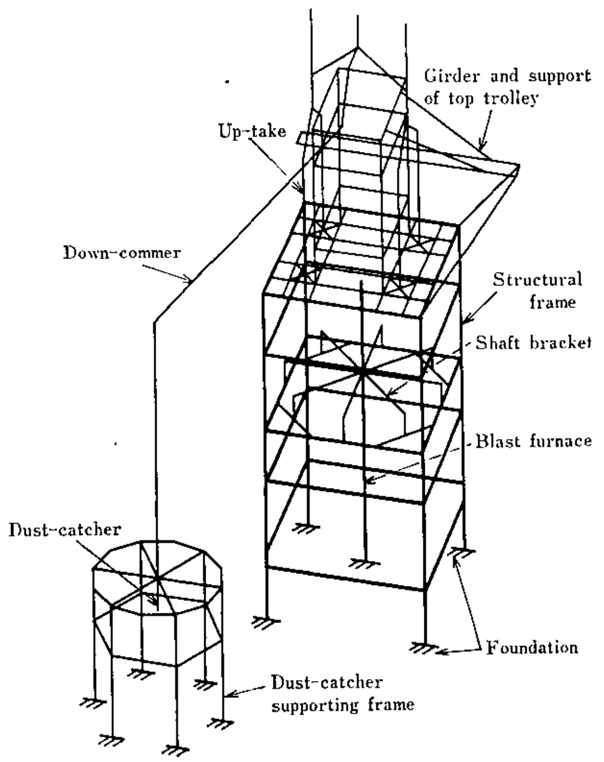

Fig. 9 Model for framed structure analysis

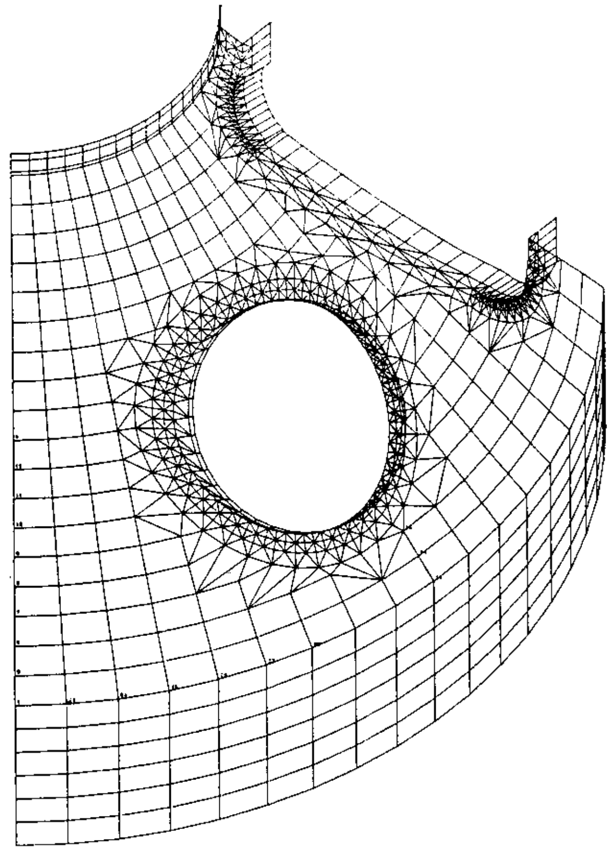

Fig. 11 Model for stress analysis of furnace top shell

4.5 Shell Stress Analysis

Since there are openings of cooling equipment, tuyere openings, tapholes, etc. in the blast furnace shell, and stress condition is complex. Therefore, a shell stress analysis is performed to know the stress condition in ligaments and the stress concentration condition at opening edges.

Figure 10 shows an example of model for shell stress analysis on shell openings. **Figure 11** shows an example of model for stress analysis of furnace top shell.

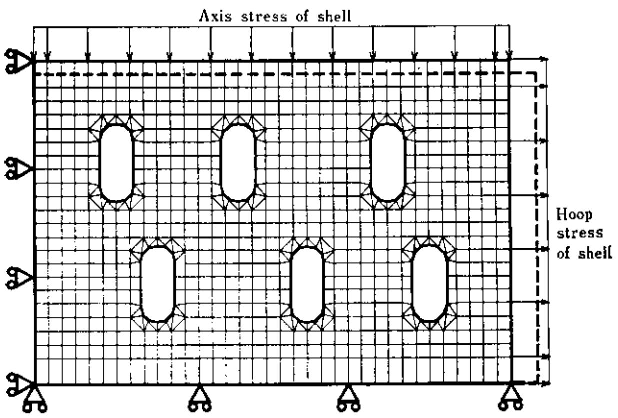

Fig. 10 Model for shell stress analysis

Ligament stress data and stress concentration data obtained by the shell stress analysis are used for the calculation of the blast furnace shell thickness.

4.6 Subsystem for Selection of Maximum Stresses in Members[2)]

In this subsystem, stresses are calculated at the stress check points of each member, the maximum value of each stress is selected in a member group, and the load case and the stress check point of the section of each member are outputted. A comparison is made between this result and the allowable stress. If necessary, the sectional shape is corrected using a display and a calculation is made again to determine a proper sectional shape.

4.7 Shell Thickness Calculation Subsystem

Figure 12 shows the flow of this subsystem. In this subsystem, the shell thickness of each calculation point is calculated by inputting the position of the point, specified allowable stresses in ligaments and

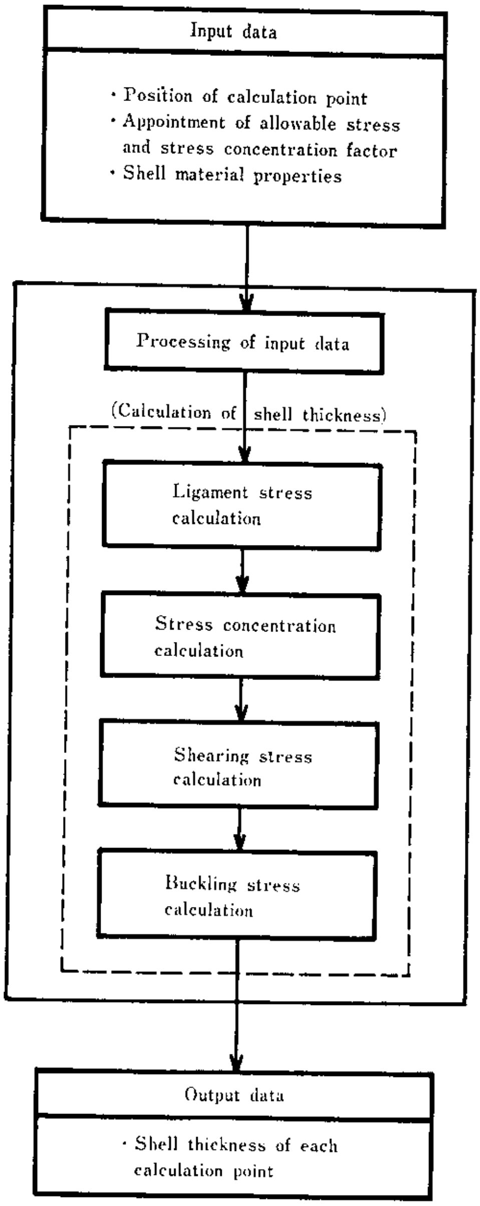

Fig. 12 Flow of shell thickness calculation subsystem

stress concentration factors, shell material properties, etc. Necessary allowable stresses in ligaments and stress concentration factors stored in data files are selected for each opening on the shell and used for the calculation.

As shown in Fig. 12, the ligament stress, stress concentration, shearing stress and buckling stress are calculated for the calculation of the shell thickness of each specified point.

Figure 13 shows an example of calculated shell thickness.

5 Effects of the KBSD system

Table 1 gives the effects of the KBSD system in a case where a structural analysis, of a 2 000 m^3 class blast furnace was made. The working hours for the analysis by the KBSD system decreases to 30% of those by the conventional analysis using NASTRAN. Furthermore, final input data of each subsystem can be stored in data files for long-term keep and can be used after a modification for the next relining; therefore, the working hours can be reduced more.

The effects of the KBSD system are as follows:

(1) Design man-hours can be reduced through a decrease in structural calculation load and calculation time. As a result, it has become possible to make advanced technical analyses.

(2) Many case studies were made and it has become possible to make designs that are optimum in terms of economy and safety.

(3) It has become possible to make up for insufficient analysis engineers if work overlaps in the construction and relining of blast furnaces.

CALCULATION POINT		KIND OF STAVE	QUALITY MATERIAL	LIGAMENT STRESS CALCULATION				STRESS CONCENTRATION CALCULATION		SHEARING STRESS CALCULATION
POINT	SIDE			BLAST LONG-TERM (MM)	BLAST SHORT-TERM (MM)	BLOW-DOWN LONG-TERM(MM)	BLOW-DOWN SHORT-TERM(MM)	BLAST BLOW-DOWN (MM)	EARTH-QUAKE (MM)	
1	UPPER	STANDARD	SM41	32.00	22.22	9.82	10.64	5.26	1.69	-
	LOWER	STANDARD	SM41	30.51	21.18	9.36	10.14	5.26	1.69	-
2	UPPER	STANDARD	SM41	33.45	23.71	11.63	14.07	5.76	2.61	-
	LOWER	STANDARD	SM41	32.09	22.55	9.77	11.77	5.77	2.30	-
3	UPPER	STANDARD	SM41	29.45	23.84	14.64	21.10	5.59	4.89	-
	LOWER	STANDARD	SM41	28.43	24.16	16.12	23.32	5.64	5.55	-
4	UPPER	TUYER	SM41	36.71	50.98	33.53	56.25	0.0	0.0	19.93
	LOWER	TUYER	SM41	36.68	49.83	33.00	55.35	0.0	0.0	
5	UPPER	TAP-HOLE	SM41	39.63	43.60	27.03	45.17	31.25	2.36	-
	LOWER	TAP-HOLE	SM41	39.63	43.60	27.03	45.17	31.25	2.36	-

Fig. 13 An example of shell thickness calculation list

Table 1 Effect of KBSD system on working hour reduction in case of 2 000 m^3

Item of calculation	Conventional structural analysis (Proportion of working hour*(%))	KBSD system (Proportion of working hour*(%))
Furnace body load calculation	21	2
Structural frame load calculation	41	11
Generating of framed structure input data and maximum stress selection of member	33	16
Shell thickness calculation	5	1
Total	100	30

* Total working hour for conventional structural analysis is assumed as 100%

(4) It has become possible to standardize analysis techniques and to prepare standardized documents.
(5) It has become possible to store structural calculation data for long-term keep and to use them effectively.

This system can be applied to other large structures of shell construction.

6 Conclusions

The structural analysis system for the construction and relining of blast furnaces (the KBSD system) was developed for the purpose of saving labor in input data preparation, efficiently evaluating analysis results and effectively utilizing NASTRAN. This system has the following features:

(1) The KBSD system is composed of the subsystems for framed structure input data generation furnace body load calculation, structural frame load calculation, selection of maximum stresses in members and shell thickness calculation, and NASTRAN.
(2) Structural calculation data can be systematically stored in data files for long-term keep and can be used also for the next relining.
(3) Standardized documents can be prepared.
(4) Being interactive, this system is efficiently operated by effective use of computers, quick response, positive data processing, etc.
(5) Since this system is composed of subsystems, it can easily be modified when calculation methods are to be changed or improved.
(6) By using this system, working hours for structural calculations can be saved by approximately 70%. Furthermore, it has become possible to reduce calculation load and make optimum designs.

Kawasaki Steel intends to expand the application of this KBSD to design systems, such as CAD systems, and systems for estimation and manufacture as a series of systematization of blast furnace relining projects.

References

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2) N. Hirai: *FACOM Journal*, **4**(1978) 8, p. 11