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# Automatic Designing and Drawing of Structures in JNR

Projet et dessins automatisés de structures à la JNR

Automatisches Entwerfen und Zeichnen von Bauwerken bei der JNR

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## I. Introduction

### 1. Construction and use of a structure and application of an electronic computer for this purpose

Construction of a structure at a given site will involve broadly the following four stages:

a) Overall planning
b) Designing
c) Construction
d) Use

Each of these stages may be subdivided and depending on the contents of these subdivisions, the electronic computer will find versatile applications.

For instance, in the stage a) different proposals are compared including the decision on the advisability of constructing a given structure at a given site. Suppose thereby the factors in planning are adequately chosen. Then it will be possible to formulate some set patterns of making comparison between different plans. If such set patterns were programmed, numerous complicated comparisons would be computerized.

Just as in the stage a), many comparative designs of a similar structure take place in the stage b), too. It is, however, in the stage of final designing that the computer best proves its worth. There is no denying that the computer is found most useful in stress calculations or calculations for selecting the dimensions. When the designing is finished, usually the plotting of a design drawing comes and even this work has come to be automatically executed by the computer in recent years. This work, however, involves extremely intricate problems not encountered in stress calculations and therefore its execution by the computer has to be preceded by most careful preparations.

The stage c) mainly represents movements of concrete objects, so it may seem that here the computer can not play any prominent role. As a matter of fact, however, there are a considerable number of cases where the computer is found useful in practical work step control and automation of construction machines. In the interest of liberating humans from unfavourable work environments, this trend will be promoted at an increased pace.

In the stage d), many examples can be cited of the computer serving for automatic operation of a structure itself like a sluice, but on the other hand a number of cases such as railway bridges may be mentioned where the collection and retrieval of information is computerized for the purpose of reflecting the past experience of maintenance and use in a new design.

2. Concrete example of automatic drawing

In the present paper a report will be made on the automatic drawing, the most unique one of the computer applications mentioned above. In Japan, automatic drawing is attempted not only JNR but also by many others such as the Construction Ministry, general contractors, bridge-builders, ship-builders and design consultants. The description here will, however, center on the practice of automatic drawing in JNR, whose design section pioneered in practical application of this technique and seemingly has the richest experience in Japan.

## II. Designing of Structures in JNR

The drawing is a mode of expressing the results of designing. At design offices which deal with numerous bridges or overbridges of similar types, different patterns of drawings are taken depending on the design systems of the structure groups to be treated. Thus it is pre-requisite for discussion on the automation of drafting to have full grasp of a design system.

1. Standardization of structures

In 1972 JNR observes the 100th anniversary of its founding. The JNR policy during this period has been consistently to standardize its structures. It is motivated by consideration of the efficiency of designing, saving of construction cost, facility of maintenance and administration, and interchangeability of structural members in the event of an emergency or for the purpose of improvement.

The first standardization ever made for designing of bridges in JNR was that of wrought iron girders 20 - 70 feet in length; this occurred in the year of 1893. Later iron was superseded by steel and now common steel is steadily yielding to high tension steel in bridge construction. Meantime, in the method of joining the structural members, riveting has been outmoded by welding and in some cases, use of high-tension bolts is beginning to be preferred. At present, for steel bridges alone there are the following standard designs available:

Steel girders - trough girder, I-beam girder, plate girders (deck and through), composite girder, pedestrian overbridge, construction girder.

Truss girders - simple support truss girders (deck and through), three-span continuous truss girder.

Similarly, for concrete bridges, too, the following standard designs have been established:

Reinforced concrete girders - slab, T-girder, H-beam embeded girder.

Reinforced concrete elevated bridge - three-span rigid frame elevated bridge (single track, double track, tangent track, curved track)

Reinforced concrete culvert - simple plate culvert, rigid frame box culvert.

Other standardizations include various abutments, piers, retaining walls, wells, inspection pits, wash stands and platforms.

Now take, for instance, deck plate girders. There are two basic load systems for them: KS-18 and KS-16. For each of these load systems there are 11 different spans ranging from 8.2 m to 46.8 m. Moreover, there are four angles of road intersection to be considered; 90°, 75°, 60°and 45°; and as many restrictions to be imposed about the height of girder. When all these items are taken into consideration, the combinations will be countless. In reality, only the most practical of them are standardized and field jobs are executed utilizing these established standards as far as possible.

As the design conditions become more elaborate to meet the field conditions better, the types of structures to be standardized increase, defeating the original purpose of standardization policy. This is an inevitable contradiction inherent in these groups of structures and there is no simple solution to the difficulty. Under the present circumstances, reconciliation of elaboration and simplification of design conditions based on experience is all we can do.

2. Standardization of design procedure

As stated above, JNR possesses a certain amount of ready design drawing for standardized structures. In the execution of a practical job the local agency in charge of the job execution applies an appropriate standard design as it is or with necessary modifications, depending on the local conditions. If in that case local engineers make such design modifications with personal approaches, the meaning of standardization will be lost. Therefore, the design procedure should be unified as far as possible to avoid personnal differences. Here lies the greatest necessity for standardizing the design procedure.

JNR now holds about 900 standard drawings of steel structures, concrete structures and earthworks, and tabulated calculation results on about 2830 cases of designing abutments and piers. These are put to practical use and according to the survey conducted in 1967 on the state of standard design application, 60 to 95 % of girders, culverts and retaining walls in the local track expansions are designed by application of the standard procedure as it is or with slight amendments, but in the similar jobs executed in suburban areas the rate of application of the standard design is a mere 10 - 60 %. Namely, about 40 - 90 % of girders, culverts and retaining walls executed in suburban areas had to be designed anew as non-standard jobs.

With progressive urbanization, this trend is likely to spread throughout the country. As a countermenasure, it has become necessary to establish a new standardized design procedure anticipating all the particular conditions happening in suburban areas, instead of the conventional practice of setting a large number of conditions in advance and selecting from among them to meet the requirements of a given job.

At present, the criteria for designing the steel structures, concrete structures and earthworks of JNR are established.

These design criteria lay down the basic principle and set rules for designing but they are not any consistent specifications for the procedures of designing various structures. The principle and rules, however, do not remain unchanged forever; they ought to keep step with theoretical evolutions and general advances in technology. On this ground JNR makes a point of reviewing these design criteria every three years.

If such a revision is relatively minor, the design criteria will be little changed. Major changes will be needed in them, however, when, for instance, the allowable stress degree is raised as the result of better materials becoming available or when a new theory on the impact or repeated load has come to be adopted. To cope with such possibilities, there is no alternative but to expedite a new designing by application of an electronic computer using a programmed standardized design procedure.

3. Automation of designing

As mentioned in the preceding section, both the structures themselves and their design procedures have been standardized, but the fact is that many non-standard designs are being made to meet the actual conditions, while there happen occasional needs to make major revisions in the already standardized designs. Here the vital point calling for serious attention of the engineers is how to revise the design procedure; to execute the calculation in accordance with the revised policy is in itself nothing sophisticated. To delegate this job of calculation to the computer, JNR is striving to realize consistent programming of the design procedures. For example, the automatic designing program for PC girders makes possible an automatic execution of the necessary calculations in accordance with the established criteria, when the computer is fed with 21 data input such as the span length, the number of main girders, the type of PC steel rod; and thereby the necessary 20 data such as the ultimate sectional dimensions, the stress degree in design section, and the PC steel consumption will be printed out by the computer. Such programs are already available for structures with a high frequency of use.

III. Automatic Drawing of Structures in JNR

1. Uses of drawing

Structure designing stage is followed by the drafting stage. The drawing of a structure expresses the conception of a structure to be build in terms of design calculations together with a list of its details and materials. The uses of such a drawing are as follows:

a) Reference for the designer in his practical work of designing.
b) Reference for the customer in signing a contract with the contractor.
c) Reference for field engineers in executing the job.
d) Reference for the structure administrator in maintaining the structure.

Naturally, a drawing with such uses is prepared with many descriptive elements to facilitate visualization of the structure to be built.

Take, for instance, a line on the drawing. It can be thick in several degrees; it can be solid, dotted, broken or one (or, two, three)-dot chain, with respective meanings. In the Japanese practice of drawing, so far as the structure design drawings are concerned, the use of colors is as a rule prohibited; and perhaps for reason of an ordinary paper with expansion and shrinkage being employed it is customary to indicate the dimensions by the dimension line and numerals; you never find the dimensions by applying a divider on the drawing and multiplying the measured result by the reduction scale factor. If the dimensions of a vital member cannot be known otherwise, the drafter of the drawing is to blame; in that case you have to consult the design calculation sheet and enter the relevant data together with the dimension line in the drawing.

This is a big difference from the electrical wiring diagram with a different use or from the drafting technique directly related to machine tools.

In recent years, however, at bridge building shops research is under way on automation of precise drawing for cutting steel plates, where by the obtained drawing is linked to a machine tool, which directly cuts the plate in accordance with the drawing. This can not however be compared to a design drawing of a structure; rather it should be regarded as a stage of material processing.

It is for reason of its great bearing on the development of automatic drafting to be described in the next section that the features of a structure drawing are discussed here.

## 2. Automation of drafting

As stated above, construction of a structure is necessarily preceded by drafting of its drawing. In recent times it rarely happens that ready-made standard drawings as they are meet the practical purposes; more often some revisions have to be made in them or a redesigning is to be made under new conditions and accordingly a new drawing has to be drafted. But variations of standard design naturally retain the original features. Take the case of a deck PC girder, for which it is common to have three drawings containing a plan view, a side elevation view, sectional views, a reinforcing bar layout with numerical data and design conditions. The modes of expression, - for instance, what sections are to be drawn or enter a side elevation view at top and a plan view below the former on the same drawing - are established in set patterns on many standard drawings. Thus main point in the drafting of such a drawing is statement of the difference in the profile or in the reinforcing bar consumption and this is nothing which needs an advanced technical decision-making. Therefore, such a job may be left to the computer and for this purpose the automation of drafting will be promoted so that the engineer may be assigned a more sophisticated duty of decision-making.

A very high level of standardization on structures and their design procedures has been quite favourable for automation of drafting, but as pointed out in the above the structure drawings have three-dimensional complex contents with many descriptive elements and it would be considerably difficult to have them drafted automatically. As to be described in the succeeding section, we began with investigation into what should be expressed and succeeded in perfecting an automatic design system.

## 3. System for automatic drafting

A block diagram showing the process of automatic drafting as practiced in JNR at present is given in Fig.1.

At 1, drafting program receives additional inputs of specific values, which are then fed to the large-side computer at 2. Thereupon, a magnetic tape 3 is produced and this goes again into a large-size computer, which produces a paper tape 4. This paper tape 4 is fed to the numerical controller 5 located by the side of the drafter 6. Then, the pen of the drafter 6, controlled by NC, traces a required drawing.

From the magnetic tape 3 branches out a graphic display 3' (GD or CRT = cathode ray tube), which serves to save time that would required for checking or debugging the program if for this purpose a drafting were repeated.

Insertion of the stage 3 (MT) instead of direct jump from 2 (large-size computer) to 4 (PT) is made for the following reasons;

1) Since the paper tape is not produced in the program-debugging stage, time can be saved and the computer efficiency can be raised.
2) With MT already available, there is freedom of producing PT at the central of terminal machine with convenient timing.
3) Work duplication necessitated by various troubles in the computer can be held to a minimum.
4) GD makes the debugging more efficient.

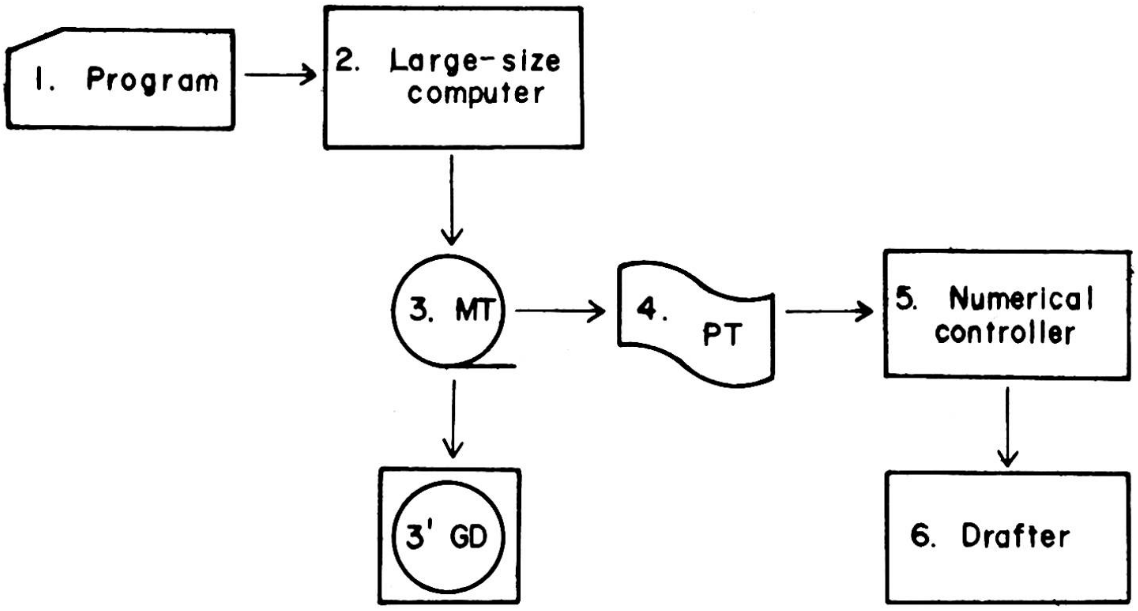



**Fig. I Block diagram of automatic drafting process**

The large-size electronic computer for this purpose is installed at the Railway Technical Research Institute, the model being FACOM-230-60. The drafter, however, is located at the Structure Design Office. Separated by about 30 km, these offices are linked by communication lines. The numerical controller is FANUC-250b, while the automatic drafter is NUMERICON.

At the Structure Design Office, there is also the terminal equipment centered around a computer called FACOM-R, which can be connected for input to or for output from the large-size computer. A similar terminal equipment is provided at the JNR Head Office and the Labour Science Institute, too.

The large-size computer at RTRI, originally intended for research use, has lately been burdened to its limit capacity with the loads originating from the Institute alone. On the other hand, the loads of calculation jobs demanded from the Structure Design Office and from the construction offices in the suburban Tokyo have reached tremendous volumes. In view of this situation it has been decided to install a new computer in the near future in the Shinjuku building which houses these offices: the model to be adopted will be FACOM-230-45 which is similar to the existing machine, ensuring the availability of existing programs.

Photo 1 reproduces the automatic drafter room and Photo 2 the automatic drafter. Figure 2 is a side elevation view, automatically drown, of prestressed concrete girder illustrated as an example.

The automatic drafting programs already developed or being developed by JNR are listed in Table 1.

The scissors crossings represents four switches coupled with two tracks. With the design of each of these switches established, this is no more than a combination of existing standards. As a mat-

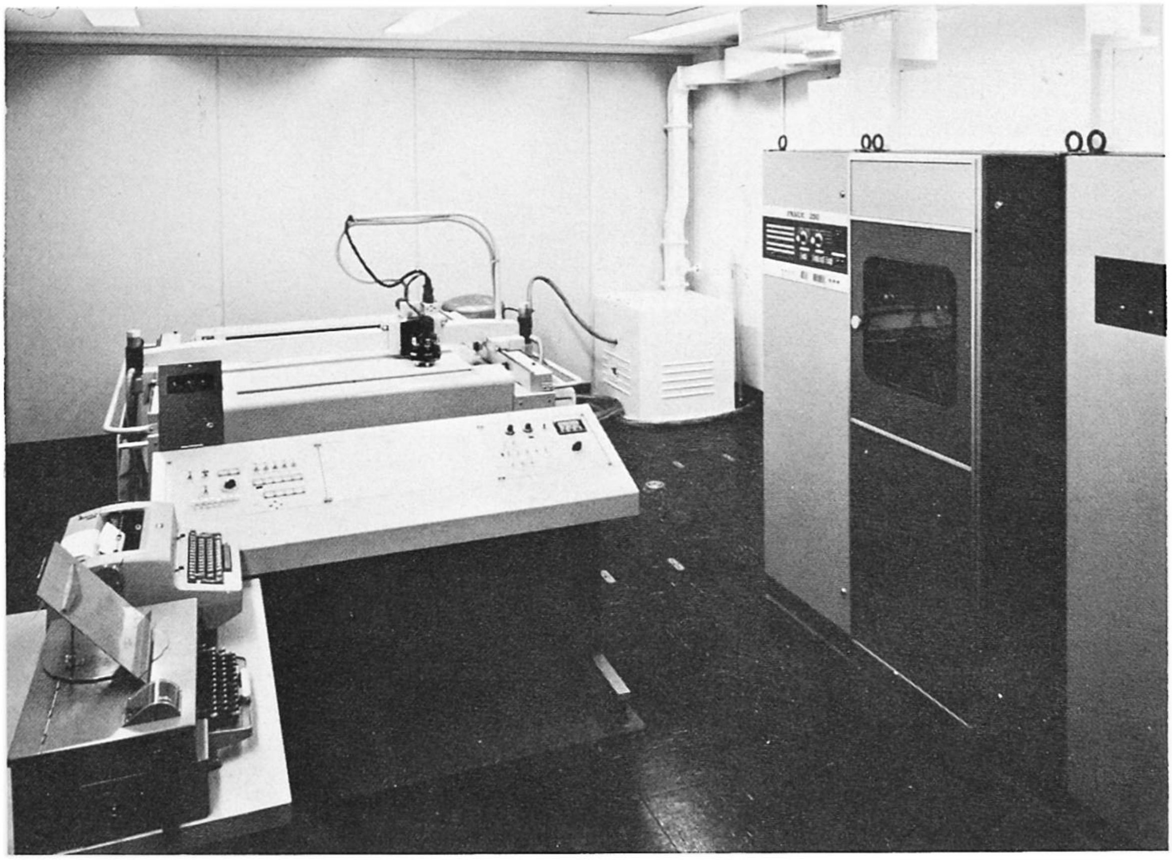


Photo 1. Automatic drafter room. Right: numerical controller; Left background: automatic drafter; Left foreground: control desk and input device

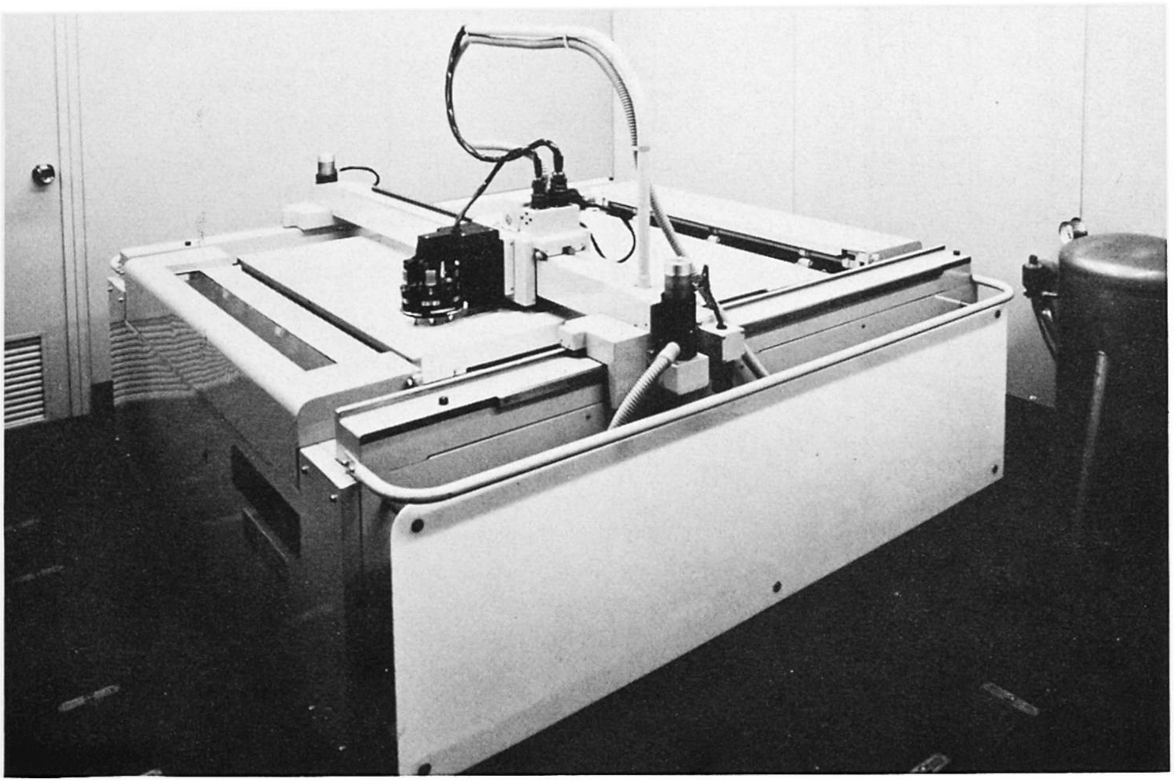
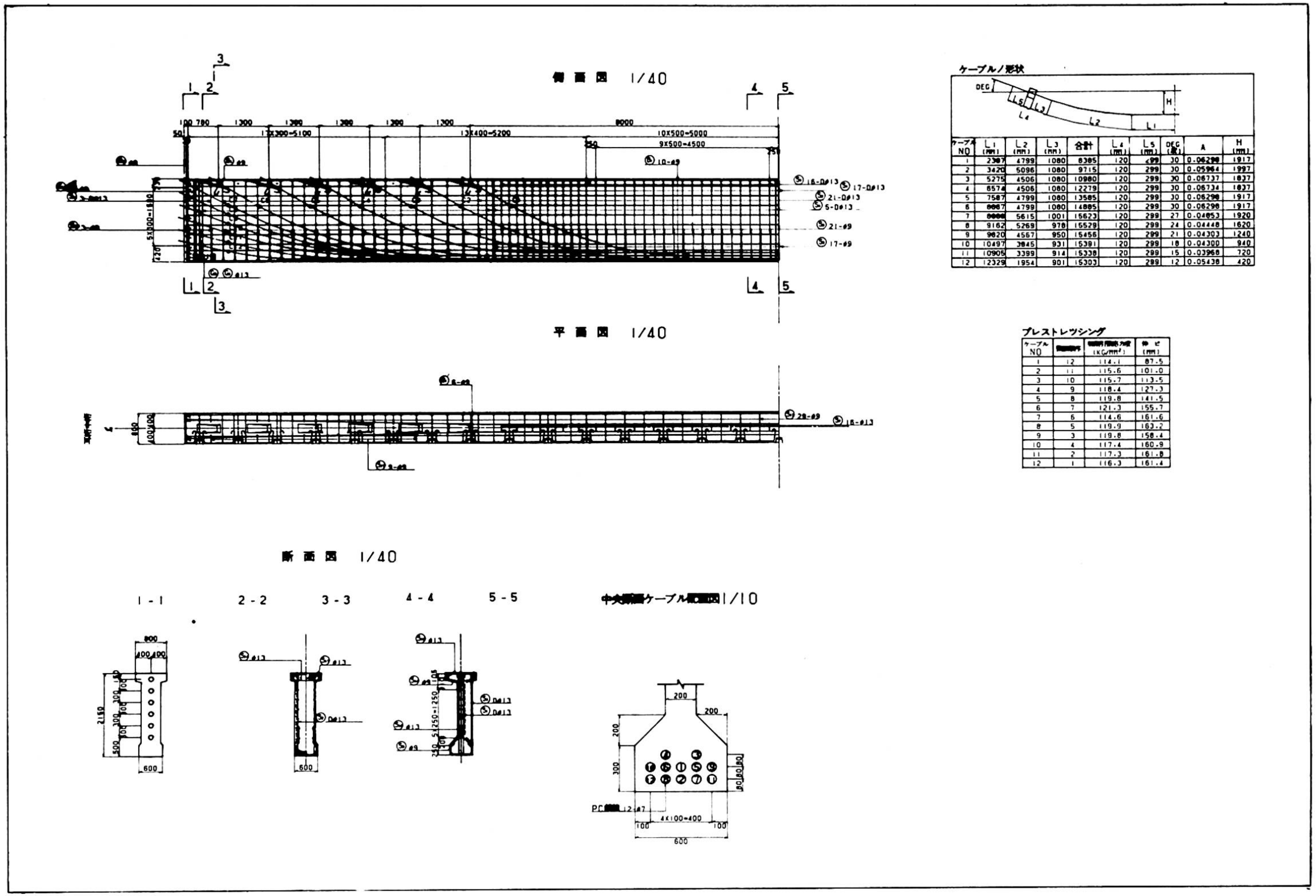


Photo 2. Automatic drafter




ケーブルノ形状

| ケーブル NO | L1 (MM) | L2 (MM) | L3 (MM) | 合計 | L4 (MM) | L5 (MM) | DEG (度) | A | H (MM) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2387 | 4799 | 1080 | 8385 | 120 | [illegible] | 30 | 0.06298 | 1917 |
| 2 | 3420 | 5096 | 1080 | 9715 | 120 | 299 | 30 | 0.05964 | 1997 |
| 3 | 5275 | 4506 | 1080 | 10980 | 120 | 299 | 30 | 0.06737 | 1837 |
| 4 | 6574 | 4506 | 1080 | 12279 | 120 | 299 | 30 | 0.06734 | 1837 |
| 5 | 7587 | 4799 | 1080 | 13585 | 120 | 299 | 30 | 0.06298 | 1917 |
| 6 | [illegible] | 4799 | 1080 | 14885 | 120 | 299 | 30 | 0.06298 | 1917 |
| 7 | [illegible] | 5615 | 1001 | 15623 | 120 | 299 | 27 | 0.04853 | 1920 |
| 8 | 9162 | 5269 | 978 | 15529 | 120 | 299 | 24 | 0.04448 | 1620 |
| 9 | 9820 | 4567 | 950 | 15456 | 120 | 299 | 21 | 0.04303 | 1240 |
| 10 | 10497 | 3845 | 931 | 15381 | 120 | 299 | 18 | 0.04300 | 940 |
| 11 | 10905 | 3399 | 914 | 15338 | 120 | 299 | 15 | 0.03968 | 720 |
| 12 | 12329 | 1954 | 901 | 15303 | 120 | 299 | 12 | 0.05438 | 420 |

プレストレッシング

| ケーブル NO | [illegible] | [illegible] (KG/MM²) | 伸ビ (MM) |
|---|---|---|---|
| 1 | 12 | 114.1 | 87.5 |
| 2 | 11 | 115.6 | 101.0 |
| 3 | 10 | 115.7 | 113.5 |
| 4 | 9 | 118.4 | 127.3 |
| 5 | 8 | 119.8 | 141.5 |
| 6 | 7 | 121.3 | 155.7 |
| 7 | 6 | 114.6 | 161.6 |
| 8 | 5 | 119.9 | 163.2 |
| 9 | 3 | 119.8 | 158.4 |
| 10 | 4 | 117.4 | 160.9 |
| 11 | 2 | 117.3 | 161.8 |
| 12 | 1 | 116.3 | 161.4 |

Fig.2 Example of automatic drafting - PC 1 - simple girder

ter of fact, however, the length of cross-over differs depending on the track separation, which is variable between 3.6 m and about 5 m.

Table 1 A list of JNR automatic drafting programs (as of Oct. 1971)

| Items | Program Name | Developed | Partially being revised | Being developed |
|---|---|---|---|---|
| Track | Special scissors crossings | ● | ● | |
| Steel structures | Deck plate girder (rectangular) | ● | ● | |
| | Through " " ( " ) | ● | ● | |
| | " " " (skew) | ● | ● | |
| | Composite girder (box) | ● | ● | |
| Concrete structures | RC box culvert | ● | | |
| | PC box girder (single-track, rectangular) | ● | | |
| | " (single-track, skew) | ● | | |
| | PC box girder (single, double-track, rectungular) | | | ● |
| | " (single, double-track, skew) | | | ● |
| | PC I-beam girder (rectangular) | ● | ● | |
| | " (skew) | ● | | |
| | RC rigid frame elevated bridge | | | ● |
| | Wing parapet | ● | | |
| | Graphical representation of FEM calculation results | ● | | |
| Building | RC multi-layer rigid frame structure layout | ● | | |

Switches, too, are different with respect to the angle, direction, right/left proportion and so on. If all conceivable combinations were taken, their number would be astronomical and it is out of the question to have all the possibilities calculated in advance. Thus the alternative is to work out calculation programs for all possible conbinations; and using them as the occasion requires, perform numerical calculations and, based on the results, make the machine automatically trace diagrams showing a general plan, skeleton, slack, bend of rail, boring position in rail, etc.

## 4. Programming system

Now the composition of the program for automatic drafting is to be described.

The automatic drafting can be programmed by FORTRAN, but FORTRAN cannot express the pen movement for drafting and for this purpose the subroutine DRF/1 has been developed.

In 1967 when JNR took to development of automatic drafting, CDC-G-20 was the only computer available; and matching this machine, at first DRF1L was developed. Subsequently, as the machine changed to 230-60, several corresponding modifications were made, producing DRF2L. However, this subroute was quite primitive in its control functions and accordingly the drafting program work turned out considerably bothering; besides, the adaptability to a model change of the computer was lacking. Thereupon, based on the idea of DRF2L and on the experience in the actual development of drafting program, a new DRF/1 was developed. The new programing system therefore has been composed as indicated in Fig. 3 in such manner as to permit use of DRF2L-based programs as they are.

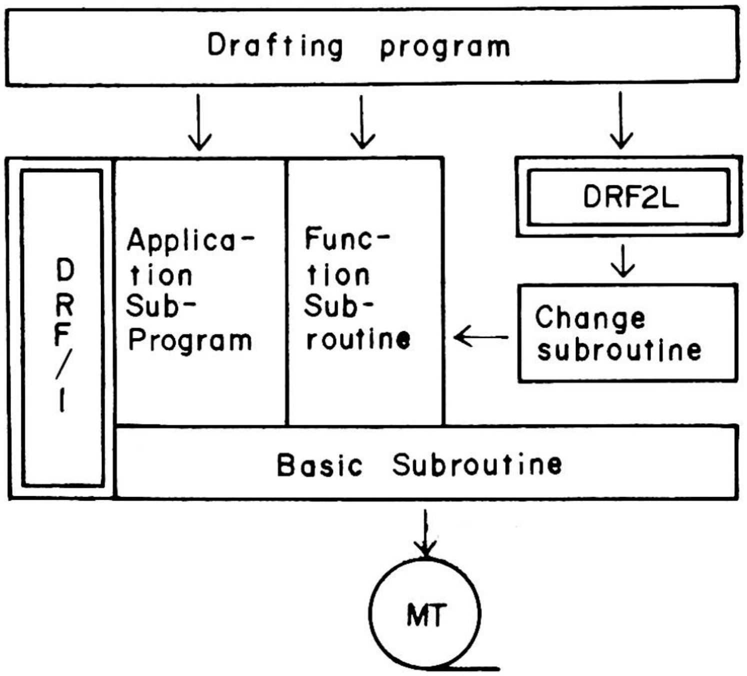


Fig.3 Drafting programming system

Generally speaking, FORTRAN and ALGOL may be regarded as language for numerical calculation. For the purpose of working out the drafting program, it is common practice to provide basic, universal subroutines with functions of coordinate calculation and graphical representation, and, with the aid of these subroutines, work out a drafting program.

Since these subroutines are intimately correlated their adequacy will largely determine the efficiency of programming work. With this in mind, utmost attention has been paid to the following points in the course of developing DRF/1:

1) DRF/1 is to be worked out as a subrouting package, so that various changes or additions in the functions may be executed easily in the form of individual revisions or addition of subroutines.

2) Automatic drafting is desirably to be linked to automatic designing. For this purpose, FORTRAN most commonly employed in JNR for design calculations is adopted as the language for DRF/1. Therefore, the subroutines for various coordinate calculations can be utilized for details calculations in the design stage.

3) In the drafting program which makes coordinate expression of figures, enormous volumes of coordinate calculations are involved. With this in mind, a large number of subroutines for coordinate calculations have been worked out to facilitate the program formulation.

4) A check routine for error message is to be attached to each of these subroutines to help debugging, because the drafting program is subject not only to errors in the use of instructions for coordinate calculations or drafting as well as to grammatical errors in common calculations. Incidentally, as mentioned in the preceding section, GD is utilized for debugging.

As illistrated in Fig.3, DRF/1 is composed of Basic Subroutine, Function Subroutine and Application Sub-program.

Basic Subroutine changes the pen shift data, etc., as calculated in Function Subroutine into a form readable by the controller of the automatic drafter, said data being written into the magnetic or paper tape, i.e., the medium of input to the controller. This part is directly linked to the automatic drafter and accordingly a change of this part will permit connection to the controller of any other model. Basic subroutine for DRF/1 comprises 14 subroutines for controlling the vertical motion of the pen and the drawing speed.

The drafting program is formulated mainly using Function Subroutine, and Basic Subroutine is used only in Function Subroutine.

Function Subroutine consists functionally of the following four parts:

1) Control subroutine

This is a command to start or end the drafting process.

2) Figure-modifying subroutine

This is a command for selecting the drawing paper size, the reduction scale, the revolution or displacement of a figure.

3) Coordinate calculation subroutine

A figure is split into dots, lines and segments for treatment and the necessary coordinates are calculated using this subroutine.

4) Figure-tracing subroutine

This is a subroutine for tracing the defined lines, segments and characters.

Application Sub-program is a sub-program which represents, using Function Subroutine, specific figures often occurring on a drawing, - for instance, arrow marks or dimension lines - in the form of a single subroutine.

Aided by Function Subroutine and Application Sub-program, the programmer works out a drafting program. At present about 70 subroutines of this kind are in use by JNR and, depending on the need more of them will be added in future.

5. Future problems

As understood from the above statement, automatic drafting is nothing easy to realize. Even the establishment of a drafting programming system as illustrated in Fig.3 has been a tremendous work and it will be still harder to work out a drafting program with application of this system. Therefore, the greater the variety of drawings that can be obtained using this hard-earned program, the better. In other words, the drafting program ought to be as universal as possible. For this purpose it would be desirable that a structure be standardized as far as possible and, even after minor modifications necessitated by the field condition, it as a whole conform to the standard pattern. Another important thing is how cleverly to standardize the figures in a drawing and how to maintain many affective Application Subprograms.

Increased applications of the computer for structure design calculations have promoted a movement to review the existing design specifications with assumed use of the computer technology, while at the same time practical application of automatic drafting has cast doubts about the established customs agreed upon in the conventional drafting method. Thus, as mentioned in III, 1, from the standpoint of drafting various customs have been submitted to reviewing. They are, however, products of long traditions and, to avoid possible chaos caused by sudden change: under a policy of gradual transition revisions were started with relatively insignificant ones. It is certainly a great improvement that too meticulous expression of unnecessary details simply by the force of habit has been considerably eliminated through these efforts.

In quest of a simpler method for formulating a drafting program than the above-mentioned automatic drafting, JNR is now developing LADD (Language for Automatic Design and Drawing), which is to be a specialized language for automatic drafting. Still under development, the whole thing cannot be introduced here, but its idea is briefly as follows.

LADD is intended for experts engaged mainly in automatic design and drawing of structures; without any more advanced training than experience in FORTRAN programming, in which most of them are trained, they will be easily able to use LADD. This is a language with geometrical concepts which will facilitate the formulation of a drafting program.

The figures around which this language is built are patters which occur repeatedly or combine to constitute larger patterns in a hierarchy.

A pre-compiler processor serves for LADD processing. At first a LADD-program is rewritten into a corresponding FORTRAN-program by the LADD processor. The FORTRAN-program thus obtained is next converted to a machine language for execution by the FORTRAN compiler. Upon completion of LADD, the formulation of a drafting program will be still easier than now.

## IV. Concluding Remark

As described above, in the fast-moving age of technical innovations JNR has energetically pushed the automation of structure design and drawing as one phase in management streamlining and modernization and these strenous efforts are steadily bearing fruit. It is a recurring question in the application of computer where the boundary should be set between the territory of humans and that of machines, but this continues to be a difficult problem to solve. Because theoretically the problem may be as simple as to couple the merits of human ability with those of computer capacity, thereby enhancing the efficiency of human thinking to a maximum, but when it comes to realization of this theory, the problem turns out far more complicated. Nevertheless, we are determined to strive undaunted toward our set aim.

Meanwhile, standardization of structures and automation of their design and drawing are feared to result in a downgrading of technical ability amont engineers. Even in the past a tendency has been noted fundamental errors being committed in the stage of its application after a standard design drawing has been established. This will not mean, however, that the policy of design standardization should be reversed. Hence the problem is how to prevent commission of such errors. It seems that the future engineers should try more to learn what is the essential thing to understand in applying the achievements in automatic design and drawing than to acquire the knowledge the past engineers were required to possess for each design job they had to work out for themselves. A new system of knowledge, which is still absent, ought to be established as soon as possible.

## Synopsis

In line with the policy of modernizing its management, JNR is striving to relieve its personnel of jobs at which humans are not so good or jobs which might as well be done by machines as by humans and, instead, to assign them with more sophisticated jobs which can be executed by only humans. Automatic design and drawing of structures is one example of achievements from these efforts. Practice of automatic drafting in JNR, the process of its development and future problems are discussed here.