한국해양공학회 2000년도 춘계학술대회 논문집 PP. 96~103

New-directional Approach : Plastic Collapse Design of Grillages

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그릴리지 구조의 소성 붕괴 설계

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KEY WORDS : Grillages 그릴리지 구조, AMDPFA 자동화 직접 소성 프레임 해석법, SST 계통적 탐사기법, GAs 유전자 알고리즘

ABSTRACT : *This research is a new design method, which will be presented as a basic concept for a more efficient minimum weight design of grillages, as an attempt to describe true collapse mechanism in as overall search as possible. It serves as introduction to the numerical technique of Linear Programming(LP) and Automatic Modified Direct Plastic Frame Analysis(AMDPFA). Attention is directed to both analysis and design, and emphasis is placed on the physical significance of Systematic Searching Techniques(SST) involved. In weight minimum grillages design, the parameterisation study in optimum beam configuration which was carried out over the range of beam sections for a given plastic section modulus likely to occur in structures by using an adaptive stochastic optimisation technique, Genetic Algorithms.*

1. Introduction

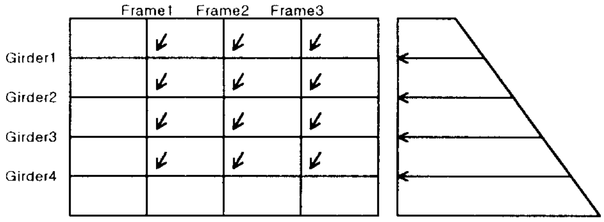
In this paper, a new design method will be presented as a basic concept for a more efficient minimum weight design of grillages. It means that collapse load, derived from applied loads, may be different over various grid configurations for the same global dimensions. Therefore, this research is an attempt to describe the true collapse mechanism(s) from all possible collapse mechanisms. It serves as introduction to the numerical techniques of Linear Programming and Automatic Modified Direct Plastic Frame Analysis(AMDPFA) programmed by the author. Attention is directed to both analysis and design, and emphasis is placed on the physical and intuitive significance of the Systematic Searching Technique (SST) developed by the author.

SST will be used systematically and intuitively to find true mechanism which has the minimum energy of the applied loading from the global collapse mechanisms of grillages. These mechanisms of any structure with the huge number of equilibrium equations consist of linear combinations of the element collapse mechanisms of each of beams.

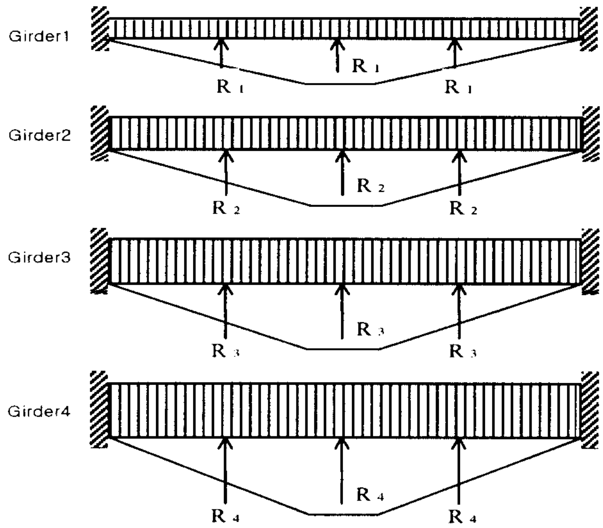
In weight minimum grillages design, the parameterisation study in optimum beam configuration which was carried out over the range of beam sections for a given plastic section modulus likely to occur in structures by using an adaptive stochastic optimisation technique, Genetic Algorithms.

2. Design for Weight Minimisation

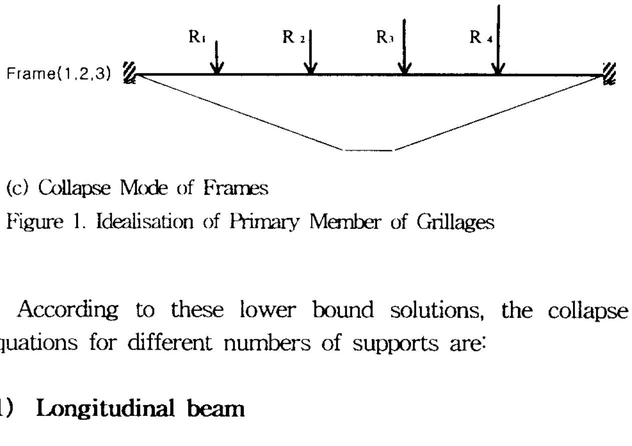
Consider grillages idealised for the beam size selection of the grillages, assuming transversals support the longitudinals, as shown Figure 1. Then using the uniqueness theorem[Neal(1977), Foulkes(1954), Kaliszky(1989)], intersection-reactions R_i at critical cross-sections, line loads along the beams, and the free and reactant bending moment diagrams are applied for all beams in either sets. In other words, the longitudinal beams are assumed to take line loads and vertical internal reactions with the same direction, while transversal beams have internal reactions of the reverse direction to that of the longitudinal beams. Collapse equations for the beams with various geometric conditions(i.e., combinations of equal and unequal geometric conditions in terms of spacing or loading) can be found by using line loads and the intersection-reaction method as fully described by Chowdhury(1985) and Kim(1982) for equal geometric conditions[Eqs. 1, 2, 4, and 5], and the current author for unequal geometric conditions[Eqs. 3 and 6].



(a) Loading and Internal-Reactions



(b) Collapse Modes of Girders



(c) Collapse Mode of Frames

Figure 1. Idealisation of Primary Member of Grillages

According to these lower bound solutions, the collapse equations for different numbers of supports are:

(1) Longitudinal beam

CASE (a) : Equal geometric conditions

$$M_p^l = \frac{(q+1)^2}{c}\left\{(1-\alpha_l)+\frac{\alpha_l^2}{(q+1)^2}\right\}w_l\cdot l_l^2 \quad (0<\alpha_l\le 1,\ q \text{ is odd}) \tag{1}$$

$$M_p^l = \frac{(q+1)^2}{c}\left\{1-\frac{q\cdot(q+2)\cdot\alpha_l}{(q+1)^2}\right\}w_l\cdot l_l^2 \quad (0<\alpha_l\le 1,\ q \text{ is even}) \tag{2}$$

where,

w_l is uniform line load intensities along long. beam(N/mm)

M_p^l is fully plastic bending moment of the long. beam(N-mm)

q is the number of tran. beams

l_l is the beam spacing of the long. beam(mm)

$\alpha_l = R/w_l l_l$ is non-dimensional parameter along long. beam

R is vertical reaction at beam intersections(N)

CASE (b) : Unequal geometric conditions

$$ {}^{l_i}_{u}M_p = \frac{1}{8}w^{l_i}\cdot LL^2+\frac{1}{2\cdot w^{l_i}\cdot LL^2}\Psi_1^2+\frac{1}{2\cdot w^{l_i}}\Psi_2^2 -\frac{1}{w^{l_i}\cdot LL}\Psi_1\cdot\Psi_2-\frac{1}{2}\Psi_1+\frac{LL}{2}\Psi_2-\Psi_3 \tag{3}$$

where,

${}^{l_i}_{u}M_p$ is plastic bending moment on u-th bay along i-th long. beam(N/mm)

$LL=\sum_{u=1}^{m} ll_u$ as total length of long. beam(mm)

ll_u is spacing at u-th bay along long. beam(mm)

w^{l_i} is line load along i-th long. beam(N/mm) ($i=1,2,\cdots,p$)

$\Psi_1=\sum_{k=1}^{u}\sum_{j=k+1}^{m} R_{(i-1)q+k}\cdot ll_j$

$\Psi_2=\sum_{k=1}^{u-1} R_{(i-1)q+k}$

$\Psi_3=\sum_{k=1}^{u-1}\sum_{r=1}^{k} R_{(i-1)q+k}\cdot ll_r$

u is any bay along long. beam ($u=1,2,\cdots,m$) ($m=q+1$)

p, q are number of long. and tran. beams

R_{iq} is vertical reaction at q-th intersection along i-th long. beam(N)

(2) Transversal beams

CASE (a) : Equal geometric conditions

$$M_p^t = \frac{(p+1)^2}{c}\left\{1+\frac{(p+1)\cdot\delta\cdot\alpha_t}{(p+1)}\cdot\frac{w_l}{w_t}\right\}w_t\cdot l_t^2 \quad (0<\alpha_t\le 1,\ p \text{ is odd}) \tag{4}$$

$$M_p^t = \frac{(p+1)^2}{c}\left\{1+\frac{p\cdot(p+2)}{(p+1)}\cdot\frac{\delta\cdot\alpha_t}{(q+1)}\cdot\frac{w_l}{w_t}\right\}w_t\cdot l_t^2 \quad (0<\alpha_t\le 1,\ p \text{ is even}) \tag{5}$$

where,

w_t is uniform line load intensities along tran. beam(N/mm)

M_p^t is fully plastic bending moment of the tran. beam(N-mm)

p is the number of long. beams

l_t is the beam spacing of the tran. beam(mm)

$\delta = L_l/L_t$ is overall grillage aspect ratio

$\alpha_t = R/w_t l_t$ is non-dimensional parameter along tran. beam

R is vertical reaction at beam intersections(N)

CASE (b) : Unequal geometric conditions

$$ {}^{t_i}_{v}M_p = \frac{1}{8}w^{t_i}\cdot TL^2+\frac{1}{2\cdot w^{t_i}\cdot TL^2}\Phi_1^2+\frac{1}{2\cdot w^{t_i}}\Phi_2^2 -\frac{1}{w^{t_i}\cdot TL}\Phi_1\cdot\Phi_2+\frac{1}{2}\Phi_1-\frac{TL}{2}\Phi_2+\Phi_3 \tag{6}$$

where,

$^{i}_{v}M_p$ is plastic bending moment on v-th bay along i-th tran. beam(N/mm)

$TL = \sum_{v=1}^{n} tl_v$ as total length of tran. beam(mm)

tl_v is spacing at v-th bay along tran. beam(mm)

w^i is line load along i-th tran. beam(N/mm) ($i=1,2,\cdots,q$)

$\Phi_1 = \sum_{k=1}^{p} \sum_{j=k+1}^{n} R_{i+(k-1)q} \cdot tl_j$

$\Phi_2 = \sum_{k=1}^{v-1} R_{i+(k-1)q}$

$\Phi_3 = \sum_{k=1}^{v-1} \sum_{r=1}^{k} R_{i+(k-1)q} \cdot tl_r$

v is any bay along tran. beam ($v=1,2,\cdots,n$) ($n=p+1$)

R_p is vertical reaction at p-th intersection along i-th tran. beam(N)

p, q are number of long. and tran. beams

In cases (a), the plastic moment can be obtained from the Eqs.(1, 2, 4, and 5) directly. In cases (b) with unequal spacing or loading, it is necessary to find all moments in any bay of beams because the plastic moments are dependent on the geometric conditions. Then the maximum moment among them will be the plastic moment.

3. Automatic Modified Direct Plastic Frame Analysis(AMDPFA)

In contrast with the step-by-step load-deflection procedure of Incremental Plastic Frame Analysis(IPFA), Direct Plastic Frame Analysis(DPFA) deals directly and effectively with the ultimate state of a structure. There is no need to examine earlier stages of the collapse or to determine the order in which the hinges are formed. In substance, DPFA is a systematic search for possible failure mechanisms and the use of some theorems, derived from equilibrium and virtual work, to determine which of the possible mechanisms corresponds to the collapse load of the structure. This smallest value of load represents the ultimate or collapse load on the true collapse mechanism among all possible mechanisms. The DPFA is referred to as Automatic Modified Direct Plastic Frame Analysis (AMDPFA) programmed by the author, because it involves the automatic calculation of the collapse load factor for possible collapse mechanisms in turn.

The procedure for AMDPFA involves the explicit calculation of the collapse load for various possible collapse mechanisms in turn, until the true mechanism is found. The possible collapse mechanisms will be searched by using the Systematic Searching Technique(SST) developed by the author. This procedure has quite important significance if we can find all possible collapse mechanisms in an m by n grid structure. Researchers mentioned that the DPFA is suitable only for hand calculation of the structure like simple plane frame and grillages[Horne(1950), Hughes1983)]. But, if it considers why this was stated, it is that more complex structures(with various geometric dimensions or boundary conditions) have many collapse mechanisms, and it was, in the past, difficult to determine all of them by hand calculation. Therefore, these problems may be overcome by using AMDPFA and SST with the linear combinations of the beam collapse mechanisms being represented by binary strings.

AMDPFA is based on the following specific assumptions:

① Prior to the appearance of the final plastic hinge, the deflections are small and have negligible influence on the equilibrium conditions of the structure.
② The value of M_p of each member is independent of the internal forces in the member
③ The members do not undergo local buckling or any other type of failure prior to the formation of a plastic hinge.
④ The members are not subject to column type of instability. Hence, the bending moment in each member is essentially independent of the normal force in the member.
⑤ The individual components of the loading always maintain the same relative proportions.
⑥ The plastic hinge moment has the same magnitude regardless of the sign of M
⑦ The deformation mode between hinges, which are developed at critical cross-section on the intersections of the members, is considered as linear.

The procedure to be followed for each of the possible collapse mechanisms is as follows:

① Note the angle of rotation at each of the plastic hinges from the collapsed configuration of the structure.
② Choose one of these angles as a reference value from geometry and express the other angles in terms of it.
③ Calculate the strain energy of deformation(rotation) at each hinge and sum these to get the total strain energy of deformation in terms of the reference rotation. If there is a discontinuity in Z_p at any of the hinge locations, the smallest value should be used in computing the value of M_p for that hinge.
④ If there are several loads, it is assumed that their relative proportions are fixed and are calculated automatically in the programme. Each component load must be depicted in the form $P_i = K_i \cdot P_{ref}$, where K_i is the proportion and P_{ref} is a reference value. Also,

from the geometry of the collapse mechanism the deflection δ_i under each component load must be expressed in terms of reference rotation.

⑤ Equate the strain energy of deformation to the work done by the load, and solve for the collapse value of the reference load P_{ref} for the assumed mechanism.

The foregoing steps can be repeated for all possible collapse mechanisms, so as to determine which mechanism has the lowest value of collapse load. But it is possible that, through an oversight in rare cases, the true mechanism might not be included among those examined. In that case the apparent collapse load -the lowest among those examined- would be too large, which is an error on the dangerous side. Therefore, it is essential to have some means for checking whether the examined collapse mechanism is the true one. For this reason, a means is suggested and done as follows. Calculate the bending moment distribution corresponding to the collapse mechanism entry, and if it does not exceed M_p at any point in the structure, then the trial mechanism is the true collapse mechanism. The above procedures will be repeated for various possible true mechanism sets, so finding which collapse mechanism has the lowest collapse load.

4. Systematic Searching Technique

4.1 Presentation due to Binary String Chromosome

The collapse mechanisms of grillages consist of the linear combinations of the beam collapse mechanisms of each of the beams, which is represented using the analogy of a binary string chromosome. It is possible to find the true mechanism which has the smallest magnitude of the applied loading from these linear combinations. To form these linear combinations, each of the beams can be depicted by using analogy from Genetics, for example, a chromosome which consists of binary strings.

The length of chromosome for a beam depends on the number of crossed intersections, and can be as follows:

$$Lch_i = 2 \cdot n_i + bc_i \qquad (7)$$

where,

Lch_i is length of the chromosome of the i-th beam

n_i is total number of intersections in the i-th beam

bc_i is number due to boundary condition of the i-th beam

- simply-support ends : $bc=0$
- each of the encastré ends : $bc=1$

Also, the total length of the structural chromosome of grillage with m beams is

$$T_{ch} = \sum_{i=1}^{m} L_{ch_i} \qquad (8)$$

where, m is the total number of beams. The total length of the structural chromosome is equal to the total number of possible hinge locations of the structure. And then, the hinge location is represented as 1(one) in a string.

The beam collapse mechanisms, represented as binary strings, can be catagorised in two ways: Global or Local. Each of them can be divided into 4 alternative strings as follows:

* *Global binary strings*
  - 1000000111 : Global Post-Eccentric Strings
  - 1110000001 : Global Pre-Eccentric Strings
  - 1000011001 : Global Mid-Eccentric Strings
  - 1100000011 : Global Symmetric Strings
* *Local binary strings*
  - 0010000111 : Local Post-Eccentric Strings
  - 0011100100 : Local Pre-Eccentric Strings
  - 0010011001 : Local Mid-Eccentric Strings
  - 0011001100 : Local Symmetric Strings

Global binary strings will be considered for this research because global collapse mechanisms with overall linear deflections are considered. The beam collapse mechanism, with encastré ends, has 4 critical-sections(hinges), and a linear deflection beam collapse mechanism. This beam collapse mechanism consists of critical-sections with 1 as the first and the last entry of the binary strings of the beam chromosome. That is, encastré ends are always critical-sections.

4.2 Constraints of the Deflection Mode

There are three kinds of constraints for the deflection modes of the beam: Equal Deflection Constraint(EDC), Cross Deflection Constraint(CDC) and Relative Deflection Constraint(RDC). These constraints are used to identify linear or non-linear deflections of the deformation shape of the structural collapse mechanism obtained due to linear combinations of beam collapse modes. Constraints are depicted as;

Equal Deflection Constraint(EDC)

The number of equilibrium equations derived from Symmetric Strings, representing Equal Deflection Constraint, is equal to the number of Symmetric Strings.

Cross Deflection Constraint(CDC)

The number of equilibrium equations for Cross Deflection Constraint, which is derived from Eccentric Strings and Symmetric Strings, are the same as the number of intersections which have no hinges.

Relative Deflection Constraint(RDC)

The number of equilibrium equations for Relative Deflection Constraints, which is derived from Eccentric Strings, is equal to the number of Eccentric Strings.

4.3 Definition of the Global Collapse Mechanism

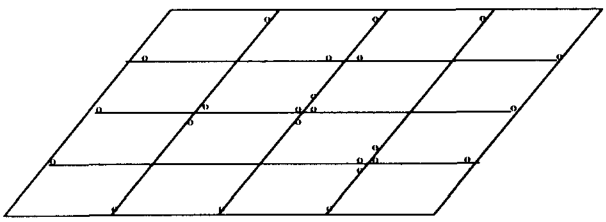
The structural collapse mechanisms consist of many possible or impossible global shape modes due to linear combinations of each of the beam collapse modes. These mechanisms of grillages, with fixed boundary condition, using AMDPFA will be searched for global collapse mechanisms which have deflections at all intersections. The definition of structural deflection modes will be mentioned as follows:

Definition of the Possible Mode

If each of beams consists of a global beam collapse mechanism(Fig. 2-a), it will always be considered as possible mode. As it were, all intersections crossing long. and tran. beams have always deflections at those joints. In another case, if any of intersections of the structural collapse mechanism(this consists of global and local beam collapse mechanism) has been balanced of deflections at those joint, it will be also considered as possible mode(Fig. 2-b).

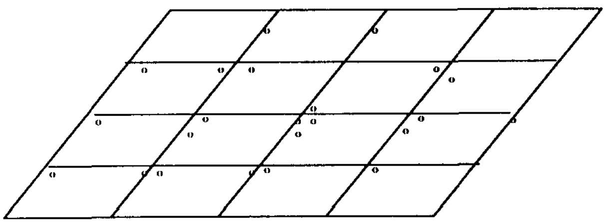
Definition of the Impossible Mode

In all of the intersections formed by crossing two beams with another beam, if any beam does not have deflections at any one of those intersections under loading, then this structural collapse mode is impossible mode(Fig. 2-c).



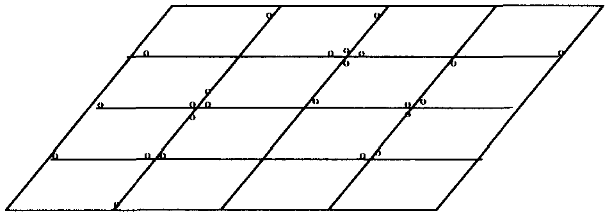
(a) Possible Mode(without Local Beam Collapse Mechanism)

(a*) 10011001 10011001 10000111
10011001 10011001 10000111



(b) Possible Mode(with Local Beam Collapse Mechanism)

(b*) 10011001 10011100 00111100
11100100 10011001 11110000



(c) Impossible Mode(with Local Beam Collapse Mechanism)

(c*) 10011001 11110000 00111100
11100100 11100100 11100100

Figure 2 Types of the structural Shape Mode
* is Binary String Chromosome for Collapse Mechanisms

4.4 Automatic Identification Method of Mechanism or Non-mechanism as Deflection Mode

The difference between mechanism and non-mechanism in global shape mode is due to the hinge distributions which can be represented as binary strings in each of the beams. That requires finding structural deflections of all the possible collapse mechanisms. It is difficult to obtain this relationship directly from the binary stings of the beams because global shape modes are presented by geometric shapes.

The following identification method is used to identify a structural collapse mechanism, which may be a linear or non-linear deflection mode: this will be achieved using a Systematic Searching Technique(SST) with an Automatic Modified Direct Plastic Frame Analysis(AMDPFA), and is described as follows;

① All component loads must be expressed as a reference value.

② Calculate the number of hinges at all intersections to find the maximum deflection joint(s) which will be the reference deflection value, δ_{ref}.

③ Determine the intersection(s)(if any), which has(have) the same deflection developed from the Symmetric strings, and develop the Equal Deflection Constraints(EDCs) from this(these) strings.

④ Develop the Relative Deflection Constraints(RDCs)(if any) from the Eccentric strings.

⑤ Calculate the deflections of the intersections in the string in each of the beam.

⑥ If any of the EDCs exist and is not satisfied, this collapse mechanism is a non-mechanism. Do not perform the following steps for the other collapse mechanisms.

⑦ If hinge(s) does not exist at any joint(say, i), compare δ_i^t from a transverse beam with δ_i^l from a longitudinal beam. If CDC is not satisfied($\delta_i^t \neq \delta_i^l$), then this possible collapse mechanism is a non-mechanism. Do not perform the following steps for the other collapse mechanisms.

⑧ Evaluate the deflections of the intersections investigated from the foregoing steps.

⑨ If RDC is not satisfied, then this possible collapse mechanism is non-linear. Do not perform the following steps for the other collapse mechanisms.

⑩ Calculate the rotations.

⑪ Calculate the Work done and the Strain energy.

⑫ Find the collapse load from step 11.

⑬ Go to step 2 for the other collapse mechanisms

5. Formulation of Design as an Optimisation problem

The weight of grillages may be determined by designing to an arbitrary limiting value of the maximum stress, σ_y (the yield stress), which, in general, may arise either in the long. or tran. beams. It is assumed that the material of both beams is identical. The weight function is mainly determined from the scantling design variables and the arranging geometric variables of a structure.

In minimum weight design by using Genetic Algorithms(GAs), the fitness evaluation involves defining an objective or fitness function against which each chromosome is evaluated for suitability for the environments under consideration. The objective function for minimum weight grillages design can be:

$$\begin{aligned} F &= TVP + TVS \\ &= TVP + TVST + TVSL \\ &= T_{plate} \cdot TL \cdot LL + A_s^t \cdot TL \cdot TB + A_s^l \cdot LL \cdot LB \end{aligned} \tag{9}$$

where,

TVP is total volume of the plate

TVS is total volume of the stiffeners

$TVST$, $TVSL$ are total volume of the tran. and long. stiffeners

T_{plate} is the thickness of the plate

TL, LL are tran. and long. length of the grillages

TB, LB are total number of the tran. and long. beams

The design parameters applied in GAs will be used to find the area of the stiffener, affecting predominently the minimum weight design of grillages, for the long. and tran. beams throught the relationship between Zp(plastic section modulus) and As(cross-sectional area of stiffners).

6. Example and Conclusion

Dimensions of an example grillages chosen for the application of the plastic analysis and design are 9*m* in breadth and 6*m* in depth. The stiffeners are constant cross-section as inverted T-section. The main emphasis of the present design study is placed on the attempt of the new plastic collapse design concept to the actual grillages design problem like as bulkheads. Therefore, the design data and beam data are chosen to generate that minimum weight design generally consists of thin plating with closely spaced stiffeners and/or beams. The beam ends are considered fixed, as the beam ends are connected to the adjacent similar structural members, and this type of end connection would resist the fully plastic bending mement.

The plate thicknesses and beam sizes are calculated due to Yield-Line theory, and due to GAs respectively. This example was achieved upto 5 by 20 grid and the numerical values in Table 1 are used for the design data.

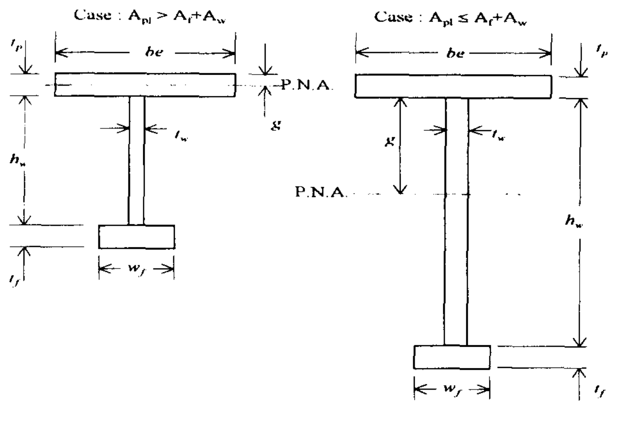
The Figure 3 shows the geometric parameters for relationship between Zp and As of beam element, and plastic section modulus(Table 2), which is derived from the geometric parameters, is used for this example.

Table 1 Data for Grillages Design

Variables	Values	Comments
L_l	9	overall logitudinal length(m)
L_t	6	overal transverse length(m)
σ_y	240	yield stress for material(MN/m^2)
$\alpha_l = \alpha_t$	1	non-dimensional intersection reaction values
$h_w/t_w = \zeta_1$	45.0	the height to thickness ratio for webs
$t_f/t_w = \zeta_4$	1.5	the thickness ratio of flange to webs
W_f/t_f	18.0	the width to thickness ratio for flange
minimum t_w	0.0	minimum thickness of webs
minimum T_p	0.0	minimum thickness of plating
p	0.030175	liquid pressure at any depth(MN/m^2)
ρ	1.025	density of liquid(ton/m^3)
g	9.81	acceleration of gravity(m/sec^2)
Totalgen	2000	the number of the total generations
Popsize	100	size of the population
C_rate	0.6	crossover rate
M_rate	0.0005	mutate rate

Table 2 Plastic section Modulus

	$A_{pl} > A_f + A_w$	$A_{pl} \le A_f + A_w$
α_1	$\frac{A_{pl} - A_w - A_f}{2 \cdot A_{pl}}$	$\frac{A_w + A_f - A_{pl}}{2 \cdot A_w}$
α_2	$\alpha_1^2 - \alpha_1 + \frac{1}{2}$	$\alpha_1^2 - \alpha_1 + \frac{1}{2}$
g	$\alpha_1 \cdot t_p$	$\alpha_1 \cdot h_w$
Z_f	$A_f \cdot \left(h_w + g + \frac{t_f}{2}\right)$	$A_f \cdot \left(h_w - g + \frac{t_f}{2}\right)$
Z_w	$A_w \cdot \left(g + \frac{h_w}{2}\right)$	$A_w \cdot h_w \cdot \alpha_2$
Z_p	$A_{pl} \cdot t_p \cdot \alpha_2$	$A_{pl} \cdot \left(g + \frac{t_p}{2}\right)$



$\zeta_1 = h_w/t_w$, $\zeta_2 = A_{pl}/A_s$, $\zeta_3 = A_f/A_w$, $\zeta_4 = t_f/t_w$, $\zeta_5 = t_p/t_w$

$A_W = \zeta_1 t^2_w$, $A_f = \zeta_1 \zeta_3 t^2_w$, $A_s = A_w + A_f = \zeta_1(1+\zeta_3) t^2_w$

Figure 3 Geometric Parameters of the Beam Element

The optimum volumes of this example grids calculated by GAs are shown in Fig. 4. The optimum volume of the grids depends on the plate thickness as can be seen in Fig. 5. The volumes of stiffeners calculated by GAs are shown in Fig. 6, and the grids with 4 beams along transverse direction tend to have the smallest volume of the stiffeners than other configurations of the grids. Fig. 7 and 8 show optimum thickness of the tran. and long. webs calculated by GAs, respectively. The collapse loads against the load applied for the *m* by *n* grids can be seen in Fig. 9.

Further Work

As a part of the trivial and private ideal of the current author, all possible hinges on structures (grillages) can be considered as sensitive parameters for identification of the structural behaviour. The object of this system identification is to identify a model that represents the structural behaviour of a given system with acceptable accuracy.

In a full model of grillages, the important parameters will be identified due to proper plastic analysis method. This reduced model will be identification of the structural behaviour once more, and the more important parameters, as significant factors forming analysis and design-oriented collapse mechanisms, will be developed.

According to these repetitive structural identification procedure, if the most important parameters(the location of hinges) can be identified, the collapse mechanisms (local or global) of any structures at collapse state will be developed due to propagation of these travelling hinges.

The different between important parameters and unimportant ones is that the former significantly may affect the deflection of the structures with intersections. Therefore, the most appropriate way to exploit this assumption and identify the important parameters, is to examine the sensitivity of the displacements of the overall structures with respect to all parameters. The objective of this idealised work is to develop that true collapse mechanism with minimum energy among the huge number of mechanisms has identified and simplified hinges on intersections of grillages structures. Therefore, for preliminary design, any of grillages structure should be defined in terms of a small number of important collapse mechanisms that further alleviates the designers job.

The development, analysis and design of these collapse mechanisms may be achieved due to *modification and supplementation of the existing* programming(SST, plastic FEM, AMDPFA, and GAs) developed and revised by the author.

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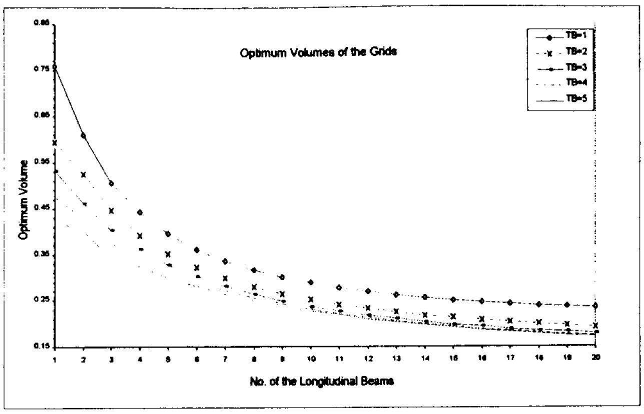

Figure 4 Optimum Volumes of the Grids calculated by Genetic Algorithms
* TB = i indicates that the number of transverse beam is i

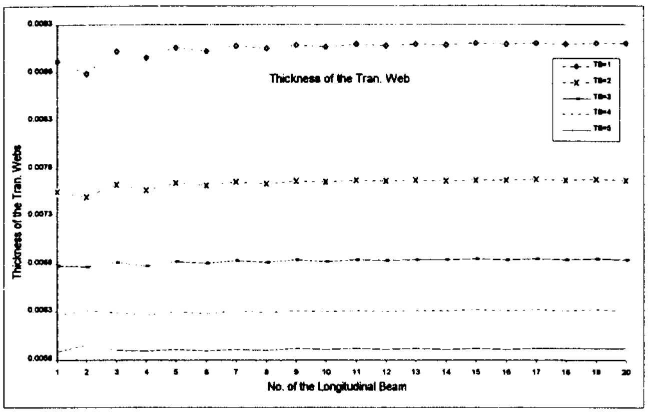

Figure 7 Optimum Thickness of the Transverse Web calculated by Genetic Algorithms
* TB = i indicates that the number of transverse beam is i

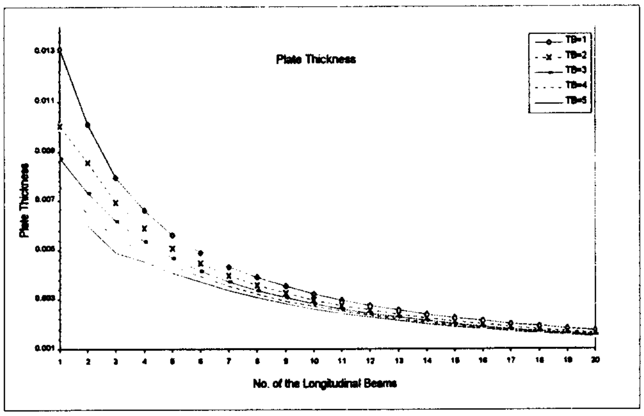

Figure 5 Plate Thickness calculated by Yield-Line Theory
* TB = i indicates that the number of transverse beam is i

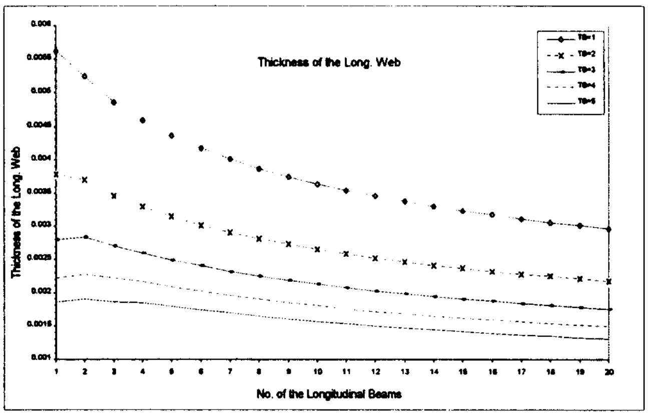

Figure 8 Optimum Thickness of the Longitudinal Web calculated by Genetic Algorithms
* TB = i indicates that the number of transverse beam is i

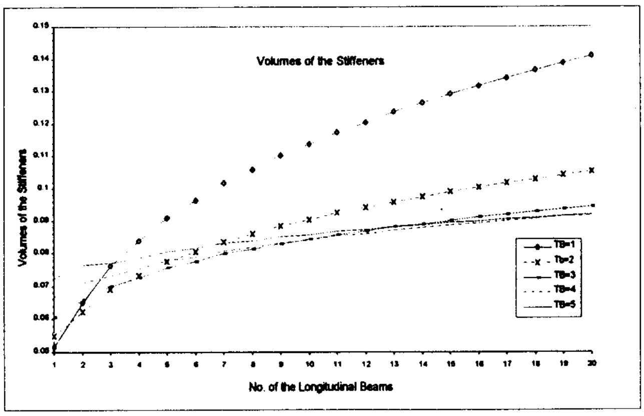

Figure 6 Volume of the Stiffeners calculated by Genetic Algorithms
* TB = i indicates that the number of transverse beam is i

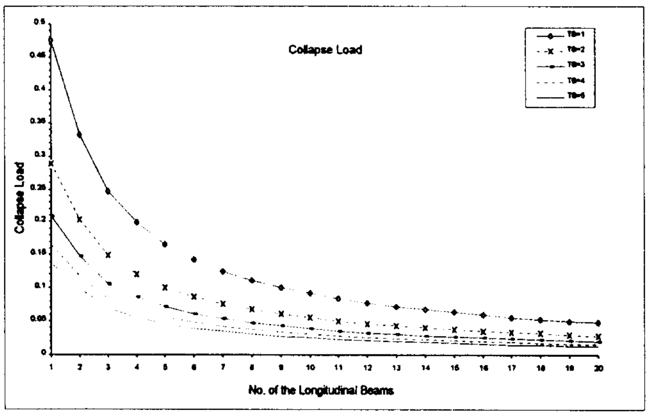

Figure 9 Collapse Load calculated by AMDPFA
* TB = i indicates that the number of transverse beam is i