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論　文　内　容　要　旨

Chapter 1. INTRODUCTION

The objective of this work are to investigate numerically the ultimate strength, deformation behavior and stress distributions in the ultimate state of thin-plate elements under shear, and to propose the ultimate shear strength formulae based on the numerical results. The thin-plate elements are the main structural members of the steel bridge girders, and the strength of them governs directly the load carrying capacity of the whole structure. The numerical analysis adopted here involves the effects of large deflection and plasticity and can trace the entire behavior up to the ultimate state of thin-plates. Based on the ultimate stress distributions obtained, a stress model at collapse is constructed, and the ultimate strength formulae are proposed. The validity of these formulae is discussed by comparison with the available experimental data and the formulae presented by other researchers. Moreover, the interactive buckling strength and the ultimate interactive strength of panel subjected to the unequal bending and shear are investigated. Finally, the shear lag phenomenon occurred in the box girder bridges which arises from the effect of shear deformation is investigated.

Chapter 2. ELASTIC-PLASTIC LARGE DEFORMATION ANALSIS OF THIN-WALLED PLATED STRUCTURES

The basic theory of numerical simulation in the elastic-plastic large deformation analysis of the plated structures is explained. It begins with the derivation of the hybrid functional in incremental from, and then a hybrid stress model is formulated. Following the explanation of the constitutive equations in the elastic-plastic problems and of the evaluation of the rigid body rotation in Updated Lagrangean formulation, the stiffness equations in the incremental form are derived and the solving procedure are outlined with some numerical technique. Some examples are illustrated in order to check the accuracy of the adopted numerical analysis and to show the validity of these numerical simulations. The suitable mesh size and type required for the parametric studies are determined throughout the convergence studies.

Chapter 3. ON THE TENSION FIELD AND COLLAPSE MECHANISM OF A PANEL UNDER SHEAR

The ultimate shear strength of an end panel isolated from a plate girder is investigated in c onjunction with the development of tension field action and the collapse mechanism. A special attention is paid to the influence of the rigidity of flanges on the behavior and strength of a web panel. The configuration of the tension field and the inclination of the tensile principal stress are revealed numerically. In the ultimate state of an end shear panel, the flange plates are not bent, and plastic hinges do not appear as reported by many researchers. Even after

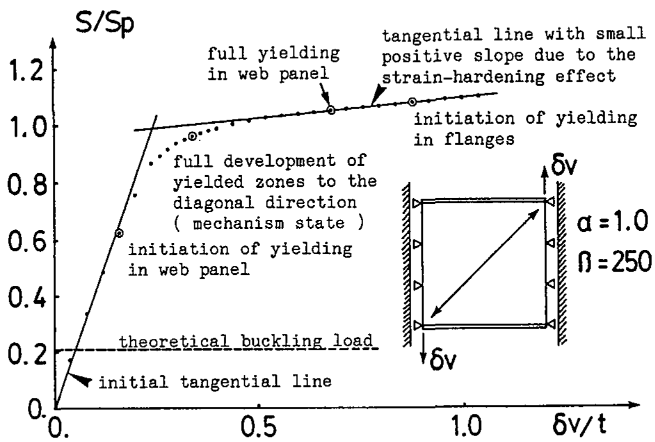

Fig.1 Development of yielded zone and collapse mechanism by displacement-control analysis (model I).

that state, there emerges the small yielded zone in them. Consequently, the shape of a web plate remains parallelogrammatic in the ultimate state. Therefore, the assumption that ultimate state is reached when the plastic hinges form in the flanges is based on the overestimation of their direct anchor action. The relationships between the configuration or the inclination of the tension field and the anchor action by the sided members or the gusset plate action, are discussed. The tension field can form without any anchor action by flanges or sided members and is anchored by the gusset plate action.

Chapter 4 . A NEW FORMULA TO PREDICT ULTIMATE SHEAR STRENGTH OF A PLATE GIRDER

Basing on the characteristics of shear strength obtained numerically, a new formula to predict the ultimate shear strength of a plate girder is proposed. A stress model in the ultimate state is constructed by the generalization of the numerically obtained stress state. The formula is expressed in a quite simple form in terms of only the shear buckling strength with the effect of flange rigidity. In order to show its validity, the predicted strength by the proposed formula is compared with those by other researchers and the available experimental data. The estimated shear strength correlates closer with the numerical results. This formula tends to yield higher strength than the experiments and other formulae, because the experiments always have the reduction of the shear buckling strength due to the bending moment. Then, a simple calculation to take into account the effect of the bending moment improves this

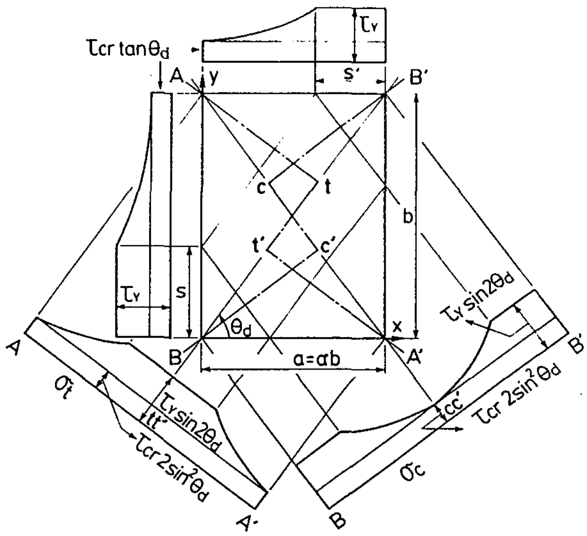

Fig.2 Stress distributions in a shear collapse model.

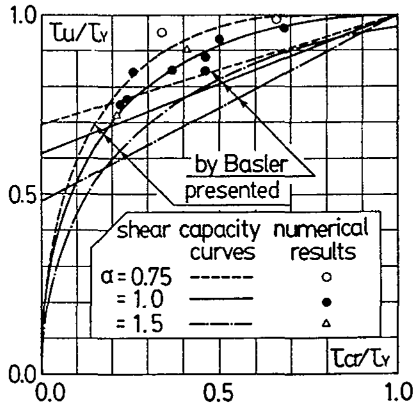

Fig.3 Comparison between numerical results and formulae for shear resisting capacity.

tendency to give the closer correlative strength and the narrower variation.

Chapter 5. ULTIMATE STRENGTH FORMULA OF A WEB PLATE UNDER COMBINED SHEAR AND BENDING

The interactive buckling strength is investigated analytically as an instability problem, in order to consider the combined loading cases for the actual girders. This buckling strength is compared with the existing interactive formula for the buckling strength of which loading condition is simplified by the constant moment and shear forces. When the larger shear force than the bending moment is applied, the shear buckling strength becomes lower than the pure bending strength owing to the appearance of secondary shear stresses induced by the unequal end moments. On the other hand, when the larger bending moment than the shear force is applied, the difference of end moments yields the increase of the interactive buckling strength in almost cases. The attention should be paid to the fact that the lower interactive buckling strength is usually obtained in the realistic range of structural paramenters, in particular of the larger aspect ratio. Moreover, the elastic post-buckling behavior is also studied in order to reveal the in-plane and out-of-plane deformation of a panel and the development of the stress distributions inside the panel. The out-of-plane deformed configurations after buckling are generally governed by the shear mode due to shear forces in the combined loading of equal end moments and shear force or due to the induced secondary shear stresses. The bending stress distributions show the lack of compressive stresses in the upper half depth of the panel due to the redistribution effect of stresses after buckling. The shearing stress distributions always

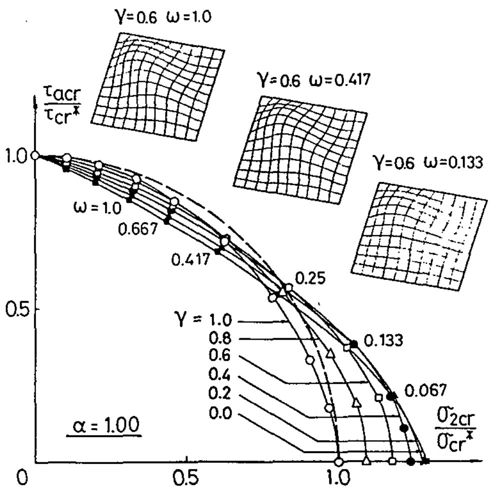

Fig.4 Interactive buckling strength diagram.

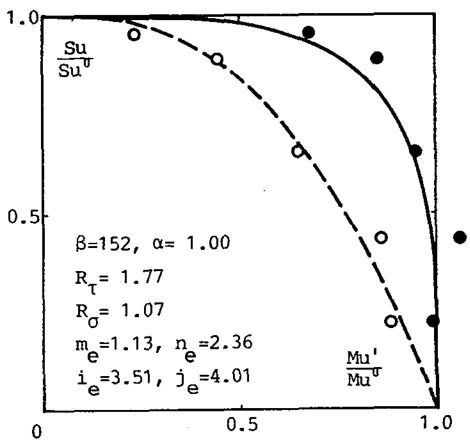

Fig.5 Ultimate interactive strength diagram with numerical results and predicted strength curves.

satisfy the mechanical boundary conditions and show a little different distributions inside the panel, but this difference is small. On the other hand, the transverse stresses occur after buckling and can not be neglected. The principal stress distributions show the stress concentration in the joint region of the compressive flange and the web plate, which causes the initiation of the yielding. The gusset plate action is also recognized in the corner region. By the numerical analysis with the rigid bar element, an ultimate interactive strength formula is presented. The design formula is constructed using a few exponential coefficients which are determined from the numerical results by the method of least squares. These coefficients are also expressed by the linear regressed function of depth-thickness parameters for the design use. From a practical point of view, this formula is easy to use because of its simple form and evaluates the strength a little conservatively. Moreover, the formula can involve the suggestion that the exponential coefficients can be taken as 4.0 as the adequate values for the actual girder strength, and is applicable to more extensive range of structural paramenters.

Chapter 6 . ANALYSIS OF ULTIMATE SHEAR LAG EFFECT IN BOX GIRDER FLANGES

The shear lag phenomenon occurred in a box girder which arises from the effect of shear deformation is investigated. The flange plate of a box girder usually has a lot of stiffening ribs, and the shear rigidity of these ribs has a great effect on the shear lag phenomenon. Therefore, the contribution of stiffening ribs of several types such as closed-section or open-section

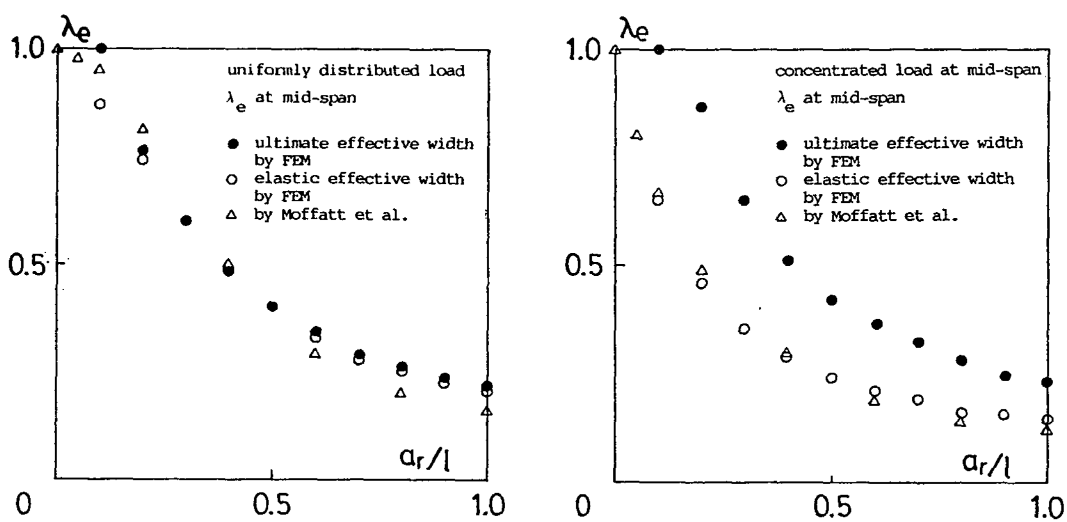

Fig.6 Relationships between ultimate effective width ratio and aspect ratio of a box girder flange.

rib is examined analytically. Governing factors for the positive and negative effective width are discussed by the parametric studies using the selected several influence parameters. The major structural parameters are the aspect ratio of a flange plate, the shear rigidity ratio and the ratio of cross-sectional area of ribs and a flange plate. The larger aspect ratio gives smaller effective width ratio, and it does not depend on the type of applied load, location to be referred along the span and applied position of the concentrated load. However, the amount of decrease of the effective width is improved by adopting T rid up to half of that obtained in the case of no shear rigidity contribution by stiffening ribs. The interaction of the plate deflection and the shear lag effect is examined by the numerical analysis up to the ultimate state for a unstiffened quarter flange plate. The reduction of effective width in the ultimate state (;i.e. ultimate effective width) due to the plate deflection becomes larger for the smaller value of the aspect ratio of a flange plate, but the differences are not so large. This ultimate effective width coincides mostly with the elastic one in the case of uniformly distributed load, while it becomes more than 50% higher value for the elastic one owing to the plastic redistribution of longitudinal stresses in the case of concentrated load.

Chapter 7. SUMMARIZED CONCLUSIONS

Main conclusions obtained in the range of this study are summarized as follows:

1) In the ultimate state of an end panel under shear, the flange plates are not bent, and no plastic hinge appears. The assumption made by some researchers that the ultimate state is reached when the plastic hinges form in the flanges is based on the overestimation of their direct anchor action.
2) The numerical simulation of the stress state in the tension field of a shear panel is utilized to construct a stress distribution model in the ultimate state. Tke stress distribution is assumed in a simple form so that the ultimate strength can be expressed in terms of the shear buckling stress only. The estimation of the shear buckling strength is improved to take account of the contribution of the flange rigidity.
3) By the analytical studies of a panel subjected to combined unequal bending and shear, the linear buckling strength characteristics are investigated more realistically. The attention should be paid to the fact that the lower interactive buckling strength is usually obtained in the realistic range of structural parameters, in particular of the larger aspect ratio.
4) A design formula of the ultimate interactive strength is constructed using a few exponential coefficients which are determined from the numerical results. These coefficients are also expressed by the linear regressed function of depth − thickness parameters for the design use. This formula is easy to use because of its simple form and can evaluate the strength a little conservatively.

5) By an analytical studies of a box girder flange with several types of ribs, the effects of selected structural parameter for the elastic effective width are investigated. The major structural parameters are the aspect ratio of a flange plate, the shear rigidity ratio and the ratio of cross-sectional area of ribs and a flange plate. The amount of decrease of the effective width is improved by adopting T rib up to half of that obtained in the case of no shear rigidity contribution by stiffening ribs.
6) A numerical analysis of the ultimate shear lag phenomenon is carried out for a quarter flange plate isolated from a simply supported beam. The ultimate effective width can be approximated by the elastic one for the uniformly distributed load, while in the concentrated loading case, it becomes more than 50% higher values compared with the elastic effective width.

審　査　結　果　の　要　旨

鋼桁橋構造を構成している薄肉鋼板の持つ大きな後座屈強度を有効利用し，より合理的な設計を可能ならしめることは，現在の構造設計の発達に資すると共に設計の自由度をも拡張させるものである。

本論文は，鋼桁構造を構成している薄板要素のせん断挙動および強度に着目し，数値解析によって後座屈挙動を追跡し，崩壊機構を解明するとともに設計に適用し得る新しい終局強度算定式の構築を目的としており，全編7章よりなる。

第1章は序論である。従来の研究を通覧し，さらに本研究の目的が述べられている。

第2章では，本研究で用いた数値解析手法の概要を説明し，さらに厳密解のあるいくつかの例題との比較により，本解析法の精度および妥当性を立証している。

第3章では，プレートガーダーの端部せん断パネルに発生する張力場と崩壊機構を数値解析により解明している。その結果，フランジには塑性ヒンジが発生しない崩壊機構となることを見い出している。よって，フランジの塑性ヒンジ発生をパネルの終局状態とみなす従来の考え方は，フランジの強度を過大評価する結果となる事を指摘した。これらは有用な知見である。

第4章では，数値解析によって得られた終局状態での応力分布を一般化することにより，崩壊時の応力モデルを独自に構築し，このモデルのとるべき張力場の傾き等を数値解析結果を通して考察している。この応力モデルから，終局せん断強度照査式をフランジ剛性の影響を考慮したせん断座屈強度のみをパラメーターとする簡潔な形で提示し，その推定せん断強度を他の研究者による強度照査式および既存の実験結果と比較検討している。これらは重要な成果である。

第5章では，実構造物が通常受ける不等曲げとせん断の組合せ荷重下でのパネルの連成座屈強度特性を解析的に明らかにし，連成座屈強度算定式を安全側に提示することに成功している。また，弾性後座屈挙動を追跡し，曲げ応力分布における応力欠損および主応力分布の観察による，いわゆるガセットプレート作用の存在等を見い出した。さらに，広範な数値解析の結果を基に，終局連成強度を相関強度式の形に纏めて提示した。これらは従来にない新しい提案である。

第6章では，ボックスガーダーのせん断遅れ現象に着目し，従来議論されてる主要影響因子以外に各種補剛リブの構造パラメータとしての特性を見い出した。また，等分布荷重に対する終局有効幅は弾性有効幅とほぼ一致するが，スパン中央集中載荷では弾性有効幅の1.5倍以上の終局有効幅が得られ，材料の塑性化による直応力の再分配効果が大きく寄 与していることを定量的に示した。

第7章は結論である。

以上要するに本論文は，鋼桁橋の中で主にせん断力の影響を受ける薄板部材の挙動，および終局強度を数値解析によって明らかにし，その結果に基づいた終局強度照査式の提案を行っており，土木工学および橋梁工学の発展に寄与するところが少なくない。

よって，本論文は工学博士の学位論文として合格と認める。