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Strengthening of Composite Girder Bridge by External Prestressing

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Summary

The aims of this paper are not only to develop a method of nonlinear analysis of prestressed composite plate girders based on the incremental deformation method but also to demonstrate the feasibility of the prestressing technique to strengthening of a existing composite girder bridge. A method of the performance evaluation and a design procedure of the prestressed composite plate girders with external tendons are proposed based on the analytical results considered with some optimum parameters which are geometric parameters and material parameters.

1. Introduction

The maintenance, repair, rehabilitation and strengthening of bridges in use around the world have been receiving more and more attention in recent years, and the deterioration of existing bridges due to increasing overloading and progressive structural aging has become a major problem. The number of heavy vehicles and volume of traffic using these bridges has come to exceed the values predicted at the time of bridge design, with the result that many of these bridges are suffering from fatigue damage and are now in urgent need of strengthening. In addition, problems can also be expected in providing suitable countermeasures for cases where revisions in the design live load exceed the present load capacity of the existing bridge. Prestressing technique can be considered as one effective method applicable in such cases[1][2]. At the same time, materials development is being actively pursued in such areas as high strength steels and continuous fiber reinforced plastics(FRP) that have high strength, outstanding corrosion resistance and high elasticity. If these materials can be successfully incorporated in prestressed composite structures, not only the strengthening of existing bridges, but the development of new bridge design configurations becomes possible. In this paper, in order to investigate the fundamental mechanical behavior of prestressed composite structures, a simply supported prestressed composite plate girder was made the subject of static behavioral analysis, taking such things as the cable arrangement and cable material as parameters. In addition, full scale tests were carried out on prestressed composite plate girders to confirm the results of the analysis. Also, with a view to evaluating methods of strengthening existing bridges, the fundamental characteristics of prestressed composite plate girders (hereafter PS composite girders), namely the yield load, ultimate load, and flexural rigidity, were evaluated. A method to improve load carrying capacity by introducing prestressing force is also proposed, based on the results of the various analyses. Also, as a numerical example, the results of applying the method to an actual bridge were studied to evaluate the performance.

2. Nonlinear Analysis of Prestressed Composite Girder and Verification Test

2.1 Fundamental Assumptions and Flow of the Analysis

The flowchart of the incremental deformation method, one means of carrying out the elasto-plastic analysis that can be applied in the case of the PS composite girder for various cable materials and arrangements, is shown in Fig. 1[3]. The details of the elasto-plastic analysis method used are described in the authors' papers[3] [4].

2.2 Outline of Verification Tests

Five test specimens were prepared for the verification tests, four PS composite girders with the queen post cable arrangement (two girders with cable within the cross section and two girders with cable arranged outside the cross section)[4], and a standard girder without cables. The specimens prepared were models of an actual composite steel plate girder bridge, the steel girder to concrete deck slab distribution ratio was made close to that of the actual bridge. As a result, the neutral axis within the elastic region of the girder lies just below the upper flange, and the cross section is very

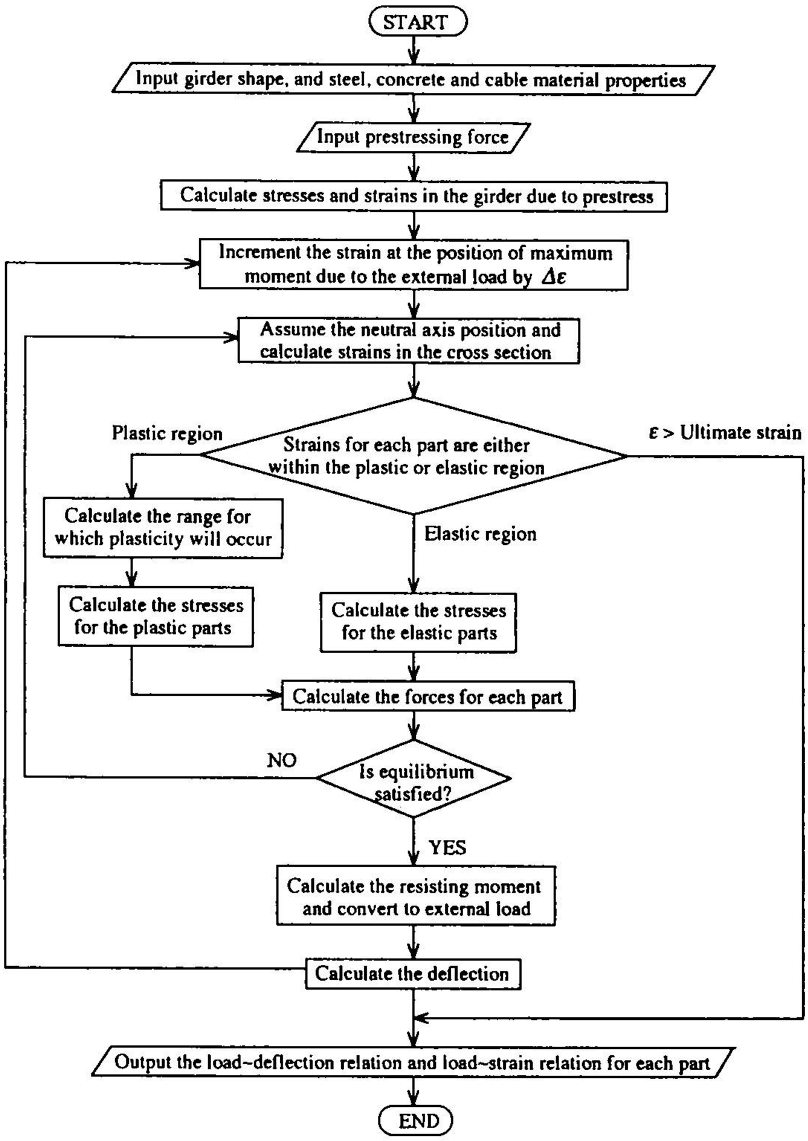


Fig. 1 Flowchart of incremental deformation method

similar to the main girder cross section of a general composite steel plate girder bridge. Commercially available H-section steel girder (SS400) was used[3], and two cable materials, PC steel cable and aramid fiber(braided cable) cable. A 50mm thick steel plate ground to form a circular arc and PVC pipe were incorporated at the position where the cable bends to provide smooth cable deflection. An outline of the different types of specimens is given in Fig. 2 and Table 1. The details of the verification method used are also described in the authors' papers[3] [4].

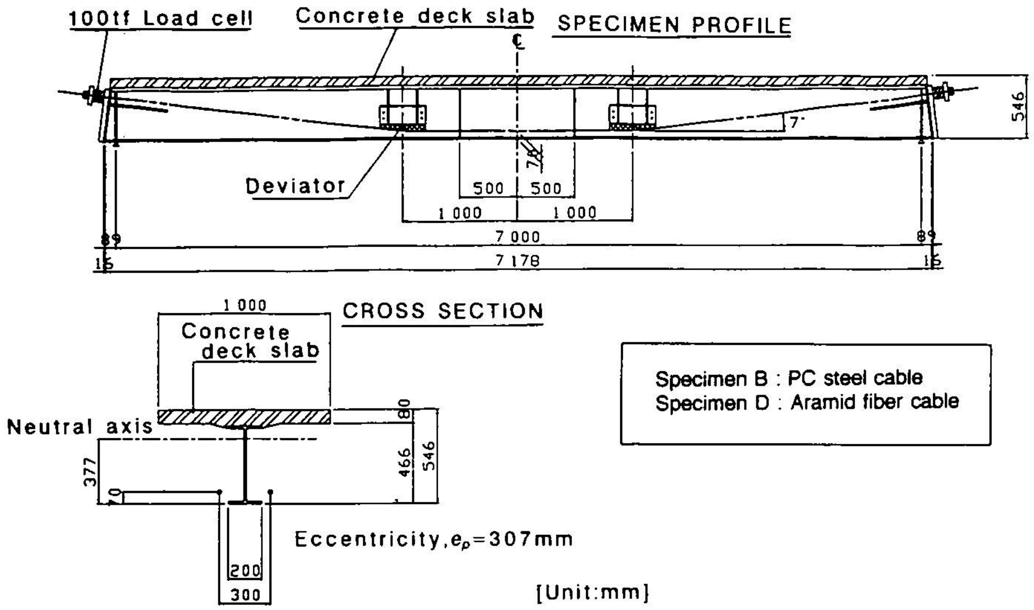


Fig. 2 Test specimen(for cables within the cross section)
Table 1 Types of specimen

Specimen	Cable arrangement	Type of cable	Initial prestressing force (Total of 2 cables, tf)
A	No cable	——	——
B	Queen-post type(Draped) Inside cross section	Steel strand	70.0
C	Queen-post type(Draped) Outside cross section	Steel strand	17.0
D	Queen-post type(Draped) Inside cross section	Aramid fiber strand	70.0
E	Queen-post type(Draped) Outside cross section	Aramid fiber strand	17.0

2.3 Comparison of Test and Analysis Results

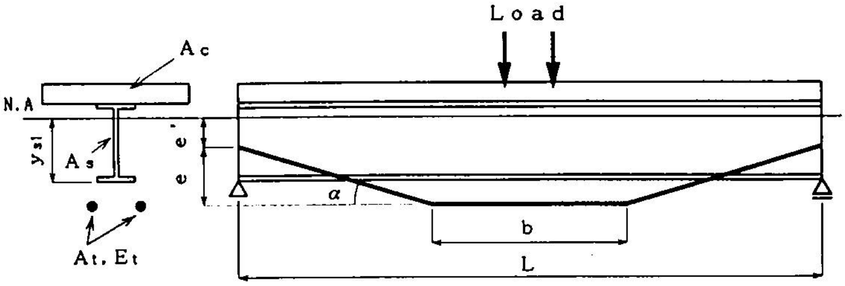
The following results can be made on overall comparison of the test results and analysis results: i) Overall, good agreement was achieved for the behavior of the load-midspan deflection relation for the test specimens. However, the value of initial gradient for the test was lower than that obtained from analysis. This can be attributed to such factors as the effective width of the concrete deck slabs at the slab center and in the region of the support points being different, ii) Small discrepancies occurred between the values of yield load and ultimate load, however, good agreement can be seen in such trends as the higher yield load being achieved in the case of cables within the cross section than outside the cross section, and lower values of yield and ultimate load occurring for low values of elastic modulus, iii) Although differences occurred in the final values of increase in the cable tension due to the differences in ultimate load, good overall agreement was achieved between the test results and the results of the analyses.

3. Performance Evaluation and Strengthening Design

3.1 Parameter Analysis and Design Procedure

For the purpose of strengthening the existing bridges indicated below, the parameters having an effect on the mechanical behavior of the PS composite girder were selected as follows, (1) b/L : Length span ratio of the horizontal portion of the cable, (2) e'/y_{s1}: Ratio of the eccentricity at the cable attachment position to the distance, from the lower surface of the bottom flange to the composite girder neutral axis, (3) e/y_{s1}: Ratio of the distance from the cable attachment position to the cable horizontal portion, to the distance from the lower surface of the bottom flange to the neutral axis, (4) E_t/E_s : Ratio of the Young's modulus of the cable to the Young's modulus of the steel, (5) A_t/A_v : Ratio of the cable cross sectional area to the composite girder cross sectional area, A_c/A_s : Ratio of the concrete deck slab cross section to the steel girder cross section. And by means of a parameter analysis, an evaluation of the performance of the PS composite girder was made in relation to improving the yield load, ultimate load and flexural rigidity. An explanation of the various symbols of the analytical model used in the analysis and details of the cross section of the composite standard girder are given in Fig. 3. In here, the dimensionless parameters (1), (2) and (3) are related to the arrangement of the cables. The dimensionless parameters (4) and (5) are related to the cable materials. The cable materials considered are generally FRP, the stress-strain relationship was assumed to vary linearly up to the point of failure[4]. The dimensionless parameter (6) relates to thickness of the deck slab, the width of the deck slab was made constant and only the thickness varied.

Fig. 4 shows a proposed design procedure for strengthening by increasing the girder yield load, based on the parameter analysis in above mentioned.



Deck slab	1000×80
Steel girder	H-450×200×9×14(SS400)
Haunch	30
Span	7000

(Unit:mm)

Fig. 3 Model symbols and section details used in parameter analysis

3.2 Numerical Example

In order to demonstrate the applicability of the method, a practical example of its application to the composite girder model of an actual bridge will be given. The bridge chosen for this was designed as a second class bridge(TL-14 load), and was a simply supported, single span, live load composite girder bridge, having 3 main girders. With the increase in traffic volume in recent years, the live load on the bridge is expected to increase to a level equivalent to that of a first class bridge. For this reason, it was decided to raise the standard of the bridge to first class bridge standard by a combination of bridge widening, the introduction of prestress, and increasing the thickness of the deck slabs. The purpose of the strengthening of this bridge is therefore to raise the class of the bridge from second to first class, in other words to increase the yield load. In order to satisfy this objective, it should be possible to apply a TL-20 load (*TL-14* x *1.43 approx.*) to the bridge without the stress in any of the bridge members exceeding the maximum allowable stress. The target value for the strengthening was set to give a yield load after strengthening of *1.4* x *the yield load* before strengthening. Also, the increase in the thickness of the concrete deck slabs was set at 8cm. According to the proposed design flow shown in Fig. 4, the various values are determined as shown in Fig. 5.

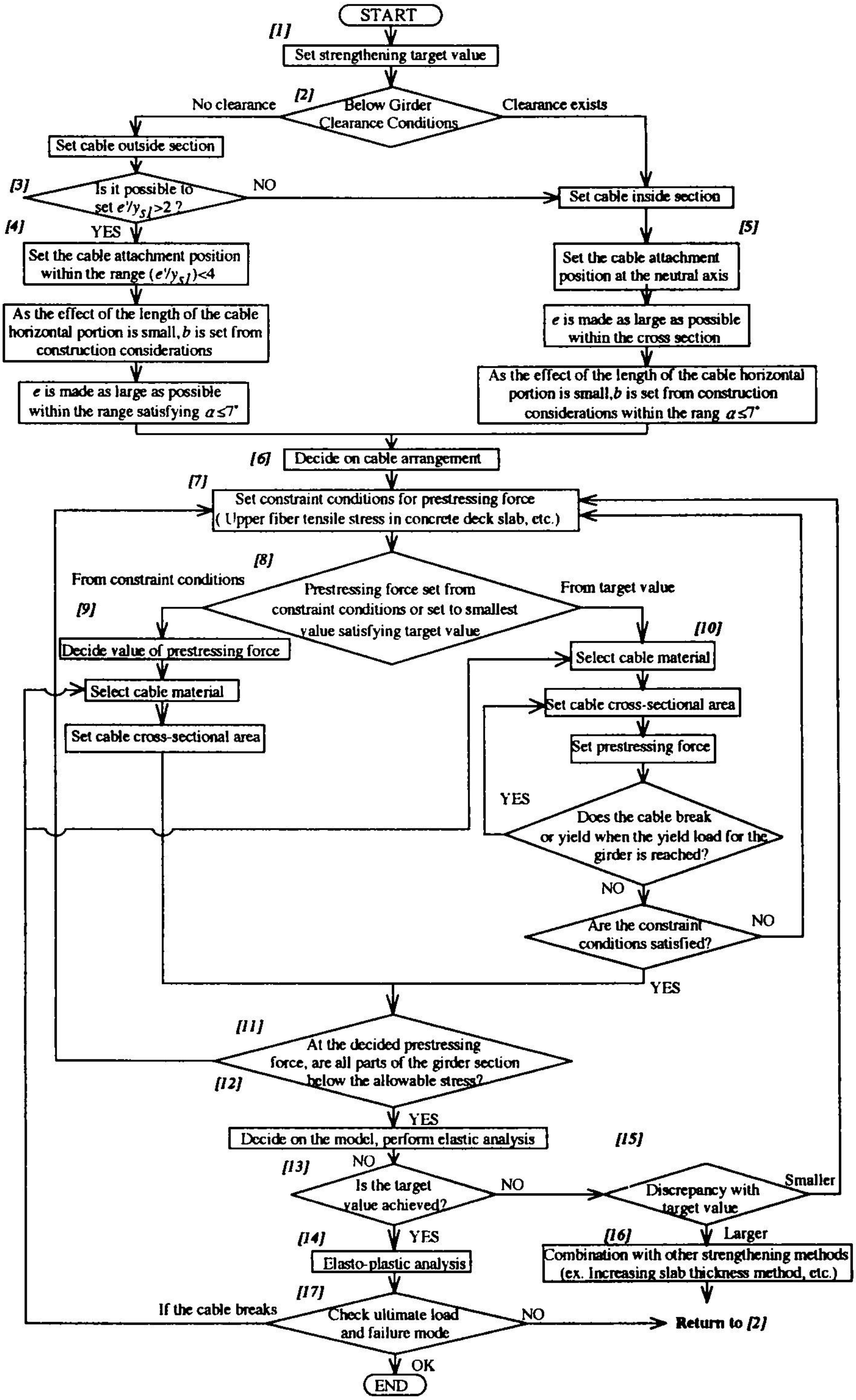


Fig. 4 Design procedure for strengthening existing bridges

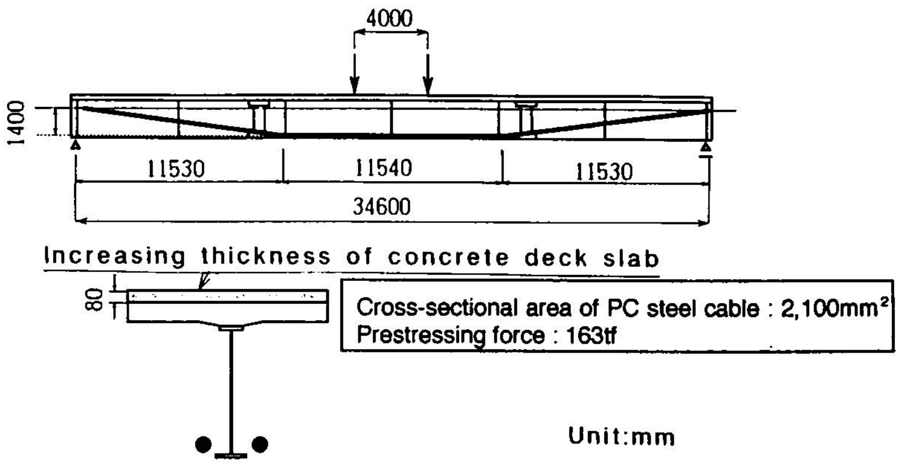


Fig. 5 Result of strengthening design by prestressing

The results of an incremental deformation method analysis performed with regard to the composite steel girder before and after the application of prestress, are shown in Table 2. From Table 2, it can be seen that the increase in yield load by a factor of 1.43 was achieved. With regard to other girder characteristics, the ultimate load was increased by a factor of 1.88, while the elastic range of the relation between the load and deflection at center span showed an improvement of 1.19 times for the gradient of the straight line portion of the curve.

Table 2 Analytical results of strengthening effect by prestressing

	Before strengthening	After strengthening (Steel strand)
Yield load (tf)	54.6	78.5 (1.44 times)
Ultimate load (tf)	96.7	181.9 (1.88 times)
Gradient of linear portion (tf/cm)	11.0	13.1 (1.19 times)

4. Conclusions

The main conclusions from this research can be summarized as follows.

1) From the experimental and analytical results, it was found that the prestressed composite girder has yield load and ultimate load superior to the standard girder, and that the performance is effected by the choice of cable arrangement and cable material.

2) With the objective of strengthening existing bridges, various dimensionless parameters were varied and an analysis made of the effects of these various parameters on the performance of the composite girder. Furthermore, a proposed design procedure based on the parameter analysis for the strengthening of existing bridges by introducing prestress to improve the yield load was successfully achieved and the efficiency of this strengthening method was adequately confirmed.

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