Steel-reinforced concrete construction

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Steel-Reinforced Concrete Construction

Construction mixte acier-béton

Stahl-Beton Verbund-Konstruktion

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Messrs. C.F. McDevitt and I.M. Viest outline very excellently the present state of the art of combining steel with concrete to form useful structural components as composite steel concrete beams, concrete encased steel beams, and steel-concrete columns. Responsing to the authors' wishes T. Naka would like to make some additional supplements to the topics described above. Since the Kanto-Earthquake occurred September 1st, 1923, almost all Japanese structural designers recognized that the composite structure having steel skeleton encased in reinforced concrete has predominantly earthquake-proof merits than any other kind of structures for multi-storeyed buildings. It behaves without serious damages under strong action of earthquake even when reinforced concrete construction shows severe cracks at columns, beam-to-column connections, shear walls, etc., which sometimes make its fatal destruction. The famous building of Nihon-Kogyo Bank, Marunouchi, Tokyo of which structure was designed by Professor Tachu Naito as steel-reinforced concrete construction with suitable shear walls showed no damages in any details of the building by the Kanto-Earthquake 1923 while in the near site Nai-Gai Building of reinforced concrete construction of about 30m height from ground level was utterly crashed down. It seems that well resistances of steel-reinforced concrete construction are due to toughness of steel skeleton after their ultimate strength of the composite structural members. Earlier papers of M. Hamada in 1929 (1) and R. Tanabashi in 1937 (2) reported that the strength and stiffeness of steel-reinforced concrete beam are almost equal to the values of reinforced concrete beam having equivalent reinforcements instead of the same area of steel skeleton. About twenty years after same results were ascertained by experimental researches of Y. Tsuboi (3), (4), T. Naito (5) and T. Naka (6), (7).

STANDARD FOR STEEL-REINFORCED CONCRETE STRUCTURE

Until 1958 there was no standard for structural calculation of steel-reinforced concrete construction and so many kinds of such composite construction were erected. This is mainly because the structural design is depending on the elastic theory and not considering the structural safety after severe deformations due to strong earthquake effects. Architectural Institute of Japan started the committee for making AIJ Standard for Structural Calculation of Steel-Reinforced Concrete Structures in 1951 to which T. Naka was the chairman and the first version of the AIJ Standard was published in 1958. The revised edition was published in 1963 while in these years many tests were carried out and their results obtained were adopted in the revised standard of AIJ. Reports by T. Naka and his staff may be shown in (8), (9), (10), (11), (12). In 1963 Ministry of Construction indicated recommendations in which multi-storeyed buildings having seven or more floors above ground level should generally have steel skeleton which would be understood as steel-reinforced concrete construction. The current officially approved standard of the construction is that of AIJ revised one in 1963. The basic principle of the standard is as follows; the standard shall be applied to the structural calculation of steel-reinforced concrete construction used generally in Japan, the part of reinforced concrete shall be designed conforming to the AIJ Standard for Reinforced Concrete Construction and the part of steel skeleton shall be designed compling with the AIJ Standard for Steel Construction excepting the requirements for local buckling of steel members which may be ignored to the steel skeleton encased in reinforced concrete. The most special features of the standard are in the assumption that the designed maximum strength of members is simply obtained by superposition of both strength of steel skeleton and reinforced concrete construction.

For beams: The section of beams shall be determined by the following formula; allowable bending moment $M = {_sM} + {_rM}$, where ${_sM}$ is allowable bending moment of steel section only and ${_rM}$ is allowable bending moment of reinforced concrete.

For columns: The section of columns shall be determined by the following formulae assuming compression to be positive, (1) when ${_rN_c} \geq N \geq {_rN_t}$, $N = {_rN}$ and $M = {_sM} + {_rM}$ and (2) when $N > {_rN_c}$ or $N < {_rN_t}$, $N = {_sN} + {_rN}$ and $M = {_sM}$, where N and M are design axial force and bending moment respectively, ${_sN}$ and ${_sM}$ are allowable axial force and bending moment of steel skeleton respectively, ${_rN}$ and ${_rM}$ are allowable axial force and bending moment of reinforced concrete respectively, ${_rN_c}$ and ${_rN_t}$ are allowable compression and tension of reinforced concrete respectively when subjected to axial force only.

For shear: $Q = {_sQ} + {_rQ}$ where ${_sQ}$ and ${_rQ}$ are allowable shear computed for steel skeleton and allowable shear computed for web reinforcing bars or adding the effects of batten plates of steel skeleton to reinforced concrete respectively.

For bond, anchorage, beam-to-column connections, joints and column bases are deliberately described in the standard.

Although the formulae of the standard are very simple in their expression they are deduced from experimental results obtained by many researchers shown in references and verified by the ultimate strength theory which was analysed by M. Wakabayashi.

Wide Flange Section and H-shape Steel Skeleton in the Composite Structures

Steel skeleton of the composite structure is now changing gradually in form and type to welded or rolled sections such as wide flange and H-shapes to make beams, columns, etc., from traditional built-up sections of riveted angles of lattice-work. Design manual of H-shape steel for the application to the composite structure is shown in references (33) and (34). Japanese Building Law and its Enforcement approve to use welding joints and connections of steel members in 1950. Since 1959 wide flange and H-shape rolled sections have been produced in Japan, the use of them accelerates the change of form and type of steel skeleton of the composite structure.

Studies upon such type of composite structures are required and some of the results obtained are shown in references (6), (21), (22), (23), (24), (25), (26), (27), (28), (29), (30).

Elasto-Plastic Behavior

For the sake of rehabitation of big cities in Japan tall buildings of dwelling houses, apartments and hotels are recently built in the type of steel-reinforced concrete construction which requires high tensile strength steel of good weldability for the skeleton and dynamic characteristics for earthquake-proof design. Damages on reinforced concrete constructions by the Tokachioki-Earthquake occurred September 16th, 1968 and by the San Fernando-Earthquake occurred February 9th, 1971 indicate that buildings should have sufficient toughness against to the severe motion induced by any earthquake. M. Wakabayashi made experimental researches to find elasto-plastic behavior of steel-reinforced concrete columns and frames under repeated loading. Fig.1 shows the test specimen and Fig.2 shows the test set-up. Load-deflection curves obtained by the tests are shown in Fig.3. Table 1 shows the test schedule. The third revised AIJ Standard for the composite structure will be issued in this year and the fourth one will be published about four years after when dynamic characteristics of the composite structure may be clarified through the serial tests upon the problems.

In the current AIJ Standard for the composite structure two requirements to the quantity of steels are specified as follows: the ratio of the total sectional area of steel members and reinforcement in axial direction of the column to the gross area of concrete should be not less than 0.8% and the ratio of the total sectional area of principal reinforcement of the column to the gross area of concrete should not be more than 4%. Regarding the steel skeleton as reinforcement the composite structure is allowed to be calculated by the AIJ Standard for Reinforced Concrete Construction, if necessary, in the current AIJ Standard for the composite structure. This case may be useful when the steel skeleton of the composite structure has an asymmetrical section or its placement is in unbalanced situation of the gross section.

Steel-Reinforced Concrete Structures in Bridge Construction

In 1927 two bridges of Melan-type were erected in Tokyo, one is Hijiri-Bashi, Ochanomizu, Hongo and another is Yaesu-Bashi, Yaesu, Nihonbashi. The former has trussed girder using L-90x90, however its structural calculation was carried as the reinforced concrete construction. Anyhow these bridges are out of the category of steel-reinforced concrete construction above written. The first experience of the composite structure was at the approach to the Saikai-Bashi, Kyushu in 1955 and the second one was at the approach to the Wakato-O-Hashi, Kyushu in 1962 both using AIJ Standard for Structural Calculation of Steel-Reinforced Concrete Structures with some modifications on allowable stresses. The Metropolitan Expressway Corporation and the Han-Shin Expressway Corporation published recently their own Standard for the composite structure (40), (41) to which M. Wakabayashi worked as a member of the committee for making the standards. Both are very similar to the AIJ Standard in principles.

J. Murata, K. Tsuno, M. Izumi and N. Yamadera are continueing their studies on the composite structures which are used in expressway construction especially. Y. Nishino is one of their research group. (36), (37), (38), (39). The application of rolled wide flange section of heavy sizes to the composite structure of civil engineering fields is becoming a big problem. M. Kokubu and others are performing their research systems and some results are shown in references. (35).

Present Discussions and Future Problems

As the design formulae are expressed in superposition of the allowable stresses of the steel skeleton and the reinforced concrete construction of the composite structures, they can cover very wide range of the ratio of the steel skeleton and the reinforced concrete construction. On the contrary, load-deflection relationship can not be obtained from these formulae. Such deficiency in the current standard of AIJ or others should be supplemented in the succeeding revised editions. One of the most important discussion in preparing the third revised AIJ Standard for the composite structure is the design formula of shear for column where $Q = {}_sQ$ should be taken disregarding ${}_rQ$ provided minimum requirements for hoops of reinforced concrete is satisfied. This proposal seems very severe for design of the composite column, however, it is intelligible by the experimental facts that almost all damages of reinforced concrete constructions by the recent earthquakes of Tokachioki 1968 and San Fernando 1971 were due to shear cracks of the columns. On the other hand the revised Standard will take into consideration of toughness of the composite structure that has great capacity of storey-drift more than 5cm without any crack in the construction. It is another problem how to evaluate the sufficient deformability of the composite structure beyond the ultimate strength without fatal collapse.

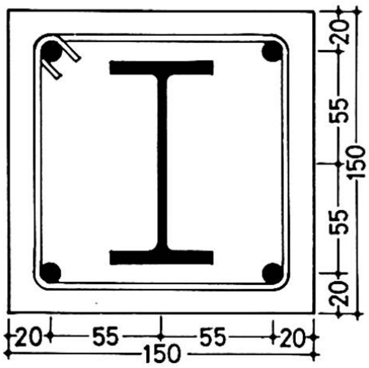


Fig. 1 Cross Section of Test Specimen

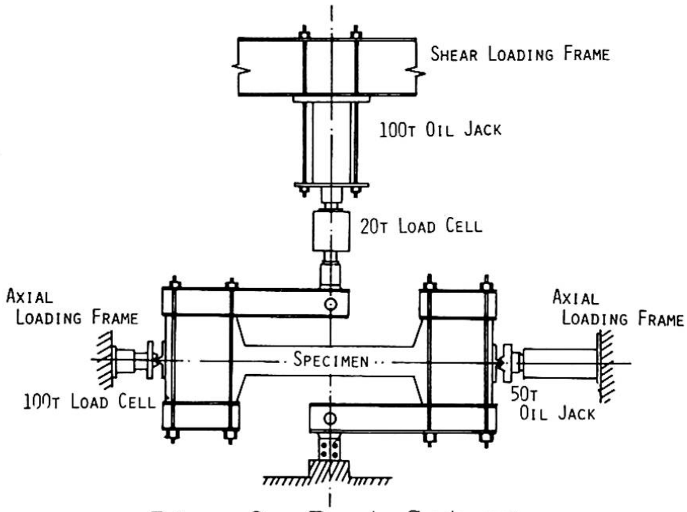
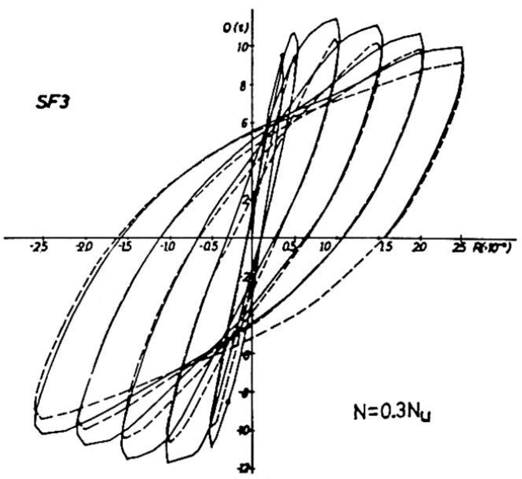


Fig. 2 Test Set-up

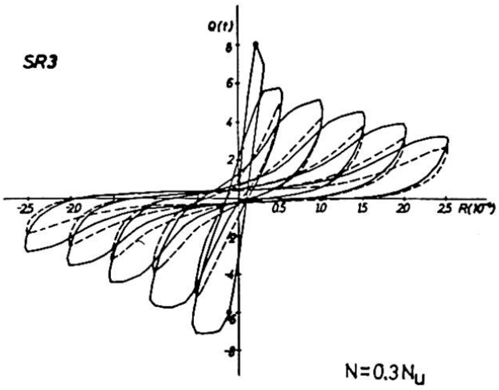
Table 1 Test Schedule

	Name of Specimen	Length (mm)	Main Reinforcing Bar	Shear Reinforcing Bar	Axial Force Ratio	Remarks
SRC (full-web)	BF 0 3 6	900	4-D10	3φ-50@	0,0.3,0.6	Bending Failure
	SF 0 3 6	450	4-D13	3φ-50@	0,0.3,0.6	Shearing Failure
SRC (open-web)	BO 0 3 6	900	4-D10	3φ-50@	0,0.3,0.6	Bending Failure
	SO 0 3 6	450	4-D13	3φ-50@	0,0.3,0.6	Shearing Failure
RC	BR 0 3 6	900	6-D13	3φ-25@	0,0.3,0.6	Bending Failure
	SR 0 3 6	450	8-D13	3φ-50@	0,0.3,0.6	Shearing Failure

Notes: Cross Section of Specimen; 150mm×150mm
Steel Reinforcement; Full-web Specimen; H-100×50×4×6, SS41
Open-web Specimen; Flange 2T-50×13×4×6, SS41
Web Width=15mm, Thickness=4mm, Pitch=75mm



(a)



(b)

Fig. 3 Load-Deflection Curve

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SUMMARY

The steel-reinforced concrete structures which are particularly developed in Japan are introduced as the most reliable earthquake-proof construction for multi-storeyed buildings.

AIJ Standard for the calculation of the composite structures is briefly described. That is depending on the ultimate strength theory and test results. Application of the composite structures to the civil engineering construction is very hopeful as design method in seismic zone in the world.