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Composite Long-Span Joists

Poutres mixtes de grande portée

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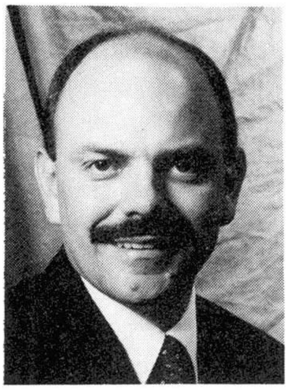

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SUMMARY

The benefits of open, essentially column free floor spaces in buildings are well recognised. Such configurations provide maximum flexibility in leasable space arrangements and thus give owners the ability to easily accommodate the request of new tenants. Composite long-span joists (trusses) are one structural system that provides these large open areas. Results of a comprehensive research program that focused on the behaviour and strength of composite long-span joists will be reviewed in this paper. Three building projects that utilise this structural system will be described.

RÉSUMÉ

L'avantage de disposer de locaux libres de colonnes est bien connu. De tels agencements offrent la plus grande flexibilité pour mettre d'importantes surfaces en location ou de les adapter aux exigences des locataires. Les poutres mixtes de grande portée (poutres et charpentes en treillis) offrent une bonne solution pour ce genre de locaux. Les auteurs présentent une vue synoptique des résultats obtenus à l'aide d'un programme de recherche sur le comportement de la résistance de poutres mixtes de grande portée. Trois projets de bâtiments illustrent l'application de ce système porteur.

ZUSAMMENFASSUNG

Der Vorteil offener, stützenfreier Räume in Gebäuden ist wohlbekannt. Derartige Anordnungen bieten dem Eigentümer grösstmögliche Flexibilität in der Bereitstellung vermietbarer Geschossfläche und der Anpassung an die Erfordernisse neuer Mieter. Weitgespannte Verbundträger (Fachwerke) sind ein mögliches Tragsystem für solche offenen Räume. Der Beitrag gibt einen Ueberblick über die Ergebnisse eines umfassenden Forschungsprogramms zum Festigkeitsverhalten von Verbundträgern grosser Spannweite. Der Einsatz dieses Tragsystems wird anhand dreier Bauprojekte geschildert.

1. INTRODUCTION

The benefits of open, essentially column free floor spaces in buildings are well recognized. Such a configuration provides maximum flexibility in leasable space arrangements and thus gives an owner the ability to easily accommodate the requests of new tenants. Composite long-span joists (light trusses) are one structural system that provides these large open areas. In addition to the benefits of column free space, the open web configuration of the joists permits easy access for mechanical and service systems, without necessarily increasing the floor-to-floor heights in the building. Both of these characteristics are significant benefits and make composite joists an economical structural system, as was realized in three recently constructed projects in the United States.

The use of composite joist systems in the U.S. is hampered by the lack of a design specification. At present, if a structural engineer wishes to consider a composite joist alternate, there are two scenarios available. One is for the engineer to use the available literature and design specifications, including those of other countries, to design a system using available cross sectional shapes. The other option is for the engineer to request design assistance from a joist manufacturer that has some experience in composite joist design. Due to the optimization inherent in joist manufacturing, the second option will likely be the most economical.

Several buildings have been constructed using composite joist or truss floor systems, most notably the Sears Tower in Chicago and the World Trade Center towers in New York. However, these composite trusses were designed by the structural engineers on the respective jobs and were unique designs. In the United States, joists or light trusses are structural elements that are manufactured in shops that are solely dedicated to this type of fabrication. This is in contrast to a conventional building fabrication shop. Joists are selected from design load tables (performance tables) developed and approved by the Steel Joist Institute (SJI).[1] The joist specifications used by the SJI closely follow the American Institute of Steel Construction (AISC) allowable stress design specification.[2] Because of the efficiency and optimization in the joist design and manufacturing process, it is unusual for joists to be independently designed by the structural engineer and fabricated in a conventional building fabrication shop. It is in the context of the U. S. design and manufacturing process that composite joists are discussed in this paper.

Results of a comprehensive research program that focused on the behavior and strength of composite long-span joists are highlighted in this paper. Also, a brief description of three building projects that utilized the composite joist floor system are presented. Finally, the present situation in the United States, with respect to composite joist design specifications, is presented.

2. RESEARCH PROGRAM

A comprehensive composite joist research program has been in progress at Virginia Polytechnic Institute for the past several years. The project has included destructive tests to evaluate strength of both full-size joists and push-out specimens, non-destructive tests to evaluate human occupant induced vibration characteristics and analytical studies using non-linear finite element analysis.

2.1 Full-Size Joist Tests

A series of 11 full-size composite joist tests have been conducted at Virginia Polytechnic Institute. The joist specimens ranged in span from 12.19 - 17.07 m and in depth from 356 - 915 mm. All joists were either a Warren or Modified Warren configuration. The loading configuration consisted of eight concentrated loads placed equidistance apart, thus approximating a uniform load arrangement. All test specimens were loaded to failure.

Comparisons were made between the predicted and experimental strength and stiffness values. The predicted values were made using procedures similar to those outlined by Chien and Ritchie.[3] Modifications to these procedures were made as outlined by Gibbings, et al. [4] and Nguyen, et al.[5] In general the results were quite acceptable, as indicated in Table 1 (see section 6. NOTATION).

TEST	M_e/M_c	I_{effe}/I_{effc}	$\Sigma Q_n/T_{bc}$	Stud Position
1	0.89	0.89	1.34	unknown
2	0.97	0.89	2.23	unknown
3	0.96	0.99	1.68	unknown
4	0.76	0.81	0.98	weak
5	0.92	0.69	1.27	strong
6	1.10	1.24	1.39	strong
7	1.15	1.07	1.38	strong
8	1.17	1.01	1.40	strong
9	1.19	0.88	1.37	alternating
10	0.93	1.04	1.03	alternating
11	0.93	0.83	0.99	alternating

Table 1 Summary of Composite Joist Tests

Test No. 4 was an exception in that the experimental-to-calculated strength ratio was lower than deemed acceptable. The behavior of this specimen was due to the placement of shear connectors in the weak position, along with having the shear connector ratio less than unity. Detailed presentations of the tests can be found in the project reports.[4,5]

2.2 Push-out Tests

During the course of the joist test program, problems were encountered in which the shear studs appeared to fail at lower than expected loads. These premature failures were primarily attributed to the influence of studs placed in the weak, or unfavorable, position. This problem led to a study of the strong vs. weak position issue,[6] which was previously identified by several other researchers. An additional project is underway at the time of this writing in which the behavior of shear studs placed in metal deck profiles is being further investigated. It is believed that the results of the current study, along with those conducted previously at Virginia Polytechnic Institute and elsewhere, will result in changes to the stud reduction factors presently used in the AISC specifications.[2,7]

2.3 Occupant Induced Vibration Studies

Because of the relatively long span of composite steel joists and corresponding large open floor areas without permanent partitions, the possibility of annoying floor vibrations caused by human activities exists. A number of tolerance criteria are used in North America to determine if a proposed floor design may be annoying to future occupants. However, all of these criteria were calibrated using floor systems with spans in the range of 6.5 - 12 m.

The criterion proposed by Murray[8] was used to evaluate the three floor systems described in the following section where spans are 15 - 36m. All three systems easily satisfied the criterion. In addition, tests of the bare floor of the Nations Bank Building (see Section 3.1 for a description) were conducted. It was determined that the calculation methods in the Murray criterion are applicable to such long-span composite joist floor systems and that the predicted human response was accurate. That is, the floor system was found to be free of annoying vibrations due to human activities. Also, no complaints have been received concerning floor motion in any of the three completed buildings described in Section 3.

3. BUILDING PROJECTS

Three building projects were constructed in the last several years in the United States that utilize composite joist floor systems. The design process for each of the three buildings was similar in that the structural engineer worked closely with the joist manufacturer. Designs according to the requirements set forth by the structural engineer of record (EOR) were carried out by the joist manufacturers' structural engineering staff and subsequently approved by the EOR.

3.1 Nations Bank Building

The Nations Bank Building, originally the Sovran Bank Building, is located in Knoxville, Tennessee. The 11 story building was designed by the office of Stanley D. Lindsey and Associates, Ltd. of Atlanta, Georgia. Composite joists are used on floors 6-11 in the office rental space, with levels 1-5 being a concrete parking structure.

The composite joists have a depth of 1,016 mm and are used for spans of 18.9 m. The joist spacing is 2,540 mm. The composite slab consists of a 76 mm deep x 0.91 mm thick composite steel deck with a structural lightweight concrete fill, yielding a total slab thickness of 160 mm. Joists were fabricated using steel with a nominal yield stress of 345 MPa and have an approximate mass per length of 50 kg/m. A total of 32 welded headed studs (19mm x 132 mm) were used as shear connectors along each joist. A more complete description of the project is given by Swensson[9].

3.2 312 Elm Street Building

The 312 Elm Street Building is located in Cincinnati, Ohio, for which the structural design was done by the office of Stanley D. Lindsey and Associates, Ltd. of Atlanta, Georgia. It is a 26 story tower with the first 10 stories being a concrete parking structure and the upper 16 stories being office rental space.

The composite joists in the building have depths of 813 mm and spans of 14.78 m. The joist spacing is 3,048 mm. The composite slab consists of a 51 mm deep x 1.1 mm thick composite steel deck with a normal weight concrete fill, resulting in a total slab thickness of 115 mm. Joists were fabricated using steel with a nominal yield stress of 345 MPa and have an approximate mass per length of 60 kg/m. A total of 32 welded headed studs (19mm x 90 mm) were used as shear connectors along each joist. A more complete description of the project is given by Corrin and Swensson[10].

3.3 Associated Wholesale Grocers Building

The Associated Wholesale Grocers Building is located in Kansas City, Missouri and was designed by the office of A. Renczarski and Co., Inc. The building is unique in that it provides two stories of office space over an existing single story structure.

A composite joist floor system was selected for the new structure, given the span requirements of 36 m. Joists with a depth ranging from 1,525 - 2,030 mm are used in the project. The joists are spaced from 2,310 - 2,565 mm. A composite floor consisting of 51 mm deep x 0.91 mm thick composite steel deck, topped with a 127 mm deep (total thickness) normal weight concrete slab is used in the building. . Joists were fabricated using steel with a nominal yield stress of 345 MPa and have an approximate mass per length of 125 kg/m. Welded headed studs (19mm x 106 mm) were used as shear connectors along each joist, with the number varying between 46 and 88.

4. DESIGN SPECIFICATIONS AND GUIDELINES

The design of composite joists is hampered in the United States by the lack of an accepted specification. However, a composite joist specification is currently under development by an American Society of Civil Engineers (ASCE) committee. Once the document is complete it will be published in the *ASCE Journal of Structural Engineering* for review and comment. Subsequently, the document may be further developed into an ASCE Standard.

The draft version of the specification is in a Load and Resistance Factor Design (LRFD) format and includes a specification, commentary and example problem. The specification draws heavily on the pioneering work done in Canada, as prescribed in the Canadian steel specification.[11] Research conducted at the University of Minnesota[12,13] and Virginia Polytechnic Institute[4-6] has also been used as support information.

A recently published design aid[14], while not a specification, provides the information necessary to make trial composite joist selections. The manufacturer's catalog was developed using available specifications, [1,2,7,11] of which only one contains information specifically for composite joists.[11] The general design procedure used to develop the design catalog was also used for the three building projects described in section 3 of this paper. The structural engineer can use the design catalog to obtain approximate designs, and thus weight (cost) estimates for a composite joist alternate. Subsequent to the initial design estimates, the structural engineer can work with the joist manufacturer to refine and optimize the design.

5. ACKNOWLEDGMENTS

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6. NOTATION

I_{effc} = calculated effective moment of inertia
I_{effe} = experimental effective moment of inertia
M_e = experimental moment capacity
M_c = calculated moment capacity
T_{bc} = bottom chord yield force (using measured material properties)
ΣQ_n = summation of shear connector strength (using measured material properties)

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