Stevin : **6.93.34/A1/11.03**

# SEMI-RIGID BEAM-TO-COLUMN CONNECTIONS

## Seventh Period 01-01-93 / 30-06-93

Aug 1993

ir. G.D. de Winkel
ir. H.D. Rink

**Project number:** DCT91.1904
**Project leader:** Prof. dr. ir. J. Wardenier

Investigation with financial aid of the Technology Foundation STW

**TU-Delft**
Delft University of Technology
Faculty of Civil Engineering
Stevin laboratory - Steel Structures
P.O. Box 5049 ; 2600 GA DELFT

| | | |
|---|---|---|
| <u>Project number</u> | : | DCT91.1904 |
| <u>Title research programme</u> | : | Semi-rigid beam-to-column connections. |
| <u>Research team</u> | : | |
| | | Paid by STW<br>ir. G.D. de Winkel: 01-01-1990 - 31-12-1993<br><br>Other members research team:<br>Prof.dr.ir. J. Wardenier (Project leader)<br>dr. Eur.-Ing. R.S. Puthli<br>ir. H.D. Rink |
| <u>Start project</u> | : | 01/01/1990 |
| <u>End of project</u> | : | 31/12/1993 |
| <u>Reporting Period</u> | : | 01/01/1993 - 30/06/1993 |
| <u>Research location</u> | : | Delft University of Technology<br>Faculty of Civil Engineering<br>Stevin II laboratory for Steel Structures |

# TABLE OF CONTENTS

# 1 EQUIPMENT AND SOFTWARE

During the report period no investments have been made and no new software has been installed. There ha been no problems with the two Sun workstations of the project.

Computer related expenses:
- 2 SDRC I-DEAS Licenses: Dfl. 9110,--

# 2 RESULTS OBTAINED IN THIS PERIOD.

## 2.1 Introduction

The numerical results and the calibration with the experiments of test series 1, axial loading tests, and of test series 2, in-plane bending tests, have been published at two international conferences.
During this reporting period the experimental tests in the framework of the relating ECSC research project have been completed. The four tests on connections with a composite steel-concrete floor has been tested. The experimental data is not completely analyzed, but the main results are available now. The tensile coupon tests are nearly finished. The data of these tests are needed for the numerical work.
The modelling of the test specimens of test series 4 have been started, but no numerical results have been obtained yet, due to errors in the used finite element program.

## 2.2 Publications

### 2.2.1 Introduction

During the report period two papers have been published at two international conferences. The first entitled "The Behaviour and Static Strength of Unstiffened I-Beam to Circular Column Connections Under Multiplanar In-Plane Bending Moments" is published at the Third (1993) International Offshore and Polar Engineering conference in Singapore, organised by the International Society of Offshore and Polar Engineers (ISOPE) (Winkel e.a., 1993a). The second paper, entitled "The Behaviour and Static Strength of Plate to Circular Column Connections under Multiplanar Axial Loadings" is published at the International Symposium Tubular Structures V in Nottingham (UK) (Winkel e.a. 1993b).

### 2.2.2 Summary "ISOPE" paper

This paper describes the behaviour and static strength of multiplanar connections between I-section beams and circular hollow section columns under various in-plane bending

moments based on numerical simulations, which are experimentally verified.
All test specimens in the work described here have the same geometrical dimensions. Of the three tests with different multiplanar in-plane bending moments on the beams, one test has an additional steel floor-plate welded to the I-section beams. For all members and the plate a steel grade equivalent to FE 510D is used.The tests have been simulated by including both geometrical and material non-linearity in the finite element analyses. In these models the actual (averaged) dimensions, weld sizes and material properties of the test specimens are included. It is shown that the numerical models are in a reasonable agreement with the experimental results.
With the calibrated model, additional load cases are analyzed, to investigate the influence of various multiplanar loading conditions on the strength and the stiffness of the connections, irrespective of variations in the measurements of dimensions and material properties between specimens. The results of the analyses with nominal dimensions will also be considered in a parameter study, which will be carried out before design guidelines can be made.

### 2.2.3 Summary "Tubular Structures V" paper

This paper forms part of a large research programme on "Semi-rigid connections between I-beams and tubular columns" and describes the behaviour and static strength of welded multiplanar connections between plates and circular hollow section columns under various axial loadings, based on experimental tests and numerical simulations. The influence of a concrete filling of the column is also taken into account. In general, there is a good agreement between the numerical and experimental results.

## 2.3 Test series 1

All experimental tests have been successfully simulated now with finite element analyzes. An overview of the test programme is shown in Table I. The results of the experimental and numerical work is listed in Table II. During the report period an explanation have been found for the relative large difference (12%) between the results of test 1C4 and the numerical model. The experimental data is further analyzed. It was found that in the compressive plates, besides the expected axial stress, there was a considerable amount of bending in the plates, likely caused by eccentricity. The combination of normal force and bending moments reduces the squash load of the plate. A small eccentricity of 5 mm causes a reduction of the squash load of 15%. In the numerical models it is difficult to obtain the same results, because eccentricies can increase during the testing. This is due the fact that the stiffness of the test rig and the lateral supports is not infinite. In the numerical models the boundary conditions are complete rigid.

## 2.4 Test series 2

The experimental tests and numerical work have been now completed and reported in the previous periods. The results of the experimental and numerical work is listed in Table II.

## 2.5 Test series 3

The experimental tests and numerical work have been now completed and reported in the previous periods. The results of the experimental and numerical work is listed in Table III.

## 2.6 Test series 4

All four experimental tests of series 4 done in the framework of ECSC research programme 7210-SA/611 have been completed in the report period.
The test specimens have a composite steel-concrete floor, comprising a deep steel deck and a reinforced slab. The slab is connected to the I-beams by means of shear studs. The webs of the I-beams are connected to a vertical plate, which is welded to the column, with a bolted connection. This connection will only take shear forces. The bottom flanges are bolted to a ring-shaped plate.
Two load cases are considered: a uni-planer loadcase, and a load case where the vertical displacements of the ends of the four I-beams were constraint. Also was varied the column, which was either steel or composite.
All test specimens failed by progressive failure of the reinforcement bars. Initially some of the bars of the reinforcement mesh failed. With continuing loading also some of the main reinforcement bars failed. The bars of the mesh failed first, because the mesh was made of cold formed steel. The main reinforcement bars were made of hot formed steel. In general, hot formed steel has more ductility than cold formed steel. The meshes with $\Phi 6$ bars, as used in the composite floor, are not available in hot formed steel.
With coming available the experimental data and the measured properties of the test specimen, the modelling of the test specimen have also been started.
Currently, no results have been achieved with the numerical simulations of the test specimens. Due to internal program errors in the finite element program the simulations could not yet be completed. Since the error type changed with the size of the finite element model, the cause of the problem could not be traced. However, since August a new version of the program is available.
The results of the experimental work is listed in Table III.

# 3 BUDGET INFORMATION

Expenses for this period:

1. Investments

   --

2. Operating costs

   Hardware service contract

   2 I-DEAS licences : f 9110.00

   Slides : f 53.00

   ===========

   Total f 9163.00

3. Travelling costs.

   --

| Statement of Expenses as on 30 June 1993 | | | | | |
|---|---|---|---|---|---|
| Items of Expenses | Budget | Balance as on 31/12/92 | Expenses from 1/1/93 to 30/6/93 | Balance as on 30/6/93 | Estimated Expenses from 1/1/93 to 30/6/93 |
| Investments | 90000.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Operation costs | 66000.00 | 45602.27 | 9163.00 | 36492.27 | * 33000.00 |
| Travelling costs | 22500.00 | 20222.67 | 0.00 | 20169.67 | ** 7500.00 |
| Total | 170000.00 | 65824.94 | 9163.00 | 56661.94 | 40500.00 |

Notes: * Dfl 30000.-- is used for additional measurements on the test specimens, which are done during 1992.

Dfl 3000,-- for Sun Hardware maintenance contract.

** Costs for attending 2 conferences.

# 4 PLANNING TIME SCHEDULE

**Period 8: Jul - Dec 1993:**

- Completion of literature survey
- Further calibrations with experimental research in the framework of the ECSC research programme (Series 4).
- More numerical simulations
- Statistical parameter study
- Start Final Report
- Paper ISOPE 94 conference

**Period 9: Jan - Jun 1994:**

- Numerical simulations
- Statistical parameter research
- Design recommendations
- Completion of the Final Report
- Paper Tubular Structures VI symposium

# 5 REFERENCES

Winkel, G.D. de, Rink, H.D., Puthli, R.S. and Wardenier, J. (1993a),"The Behaviour and Static Strength of Unstiffened I-Beam to Circular Column Connections under In-Plane Bending Moments", *Proc. 3rd Inter. Offshore and Polar Engineering Conference*, Singapore, pp. 167-174.

Winkel, G.D. de, Rink, H.D., Puthli, R.S. and Wardenier, J. (1993b), "The Behaviour and Static Strength of Plate to Circular Column Connections under Multiplanar Axial Loadings", *Proc. Tubular Structures V*, Nottingham, pp. 703-711.

# 6 TABLES

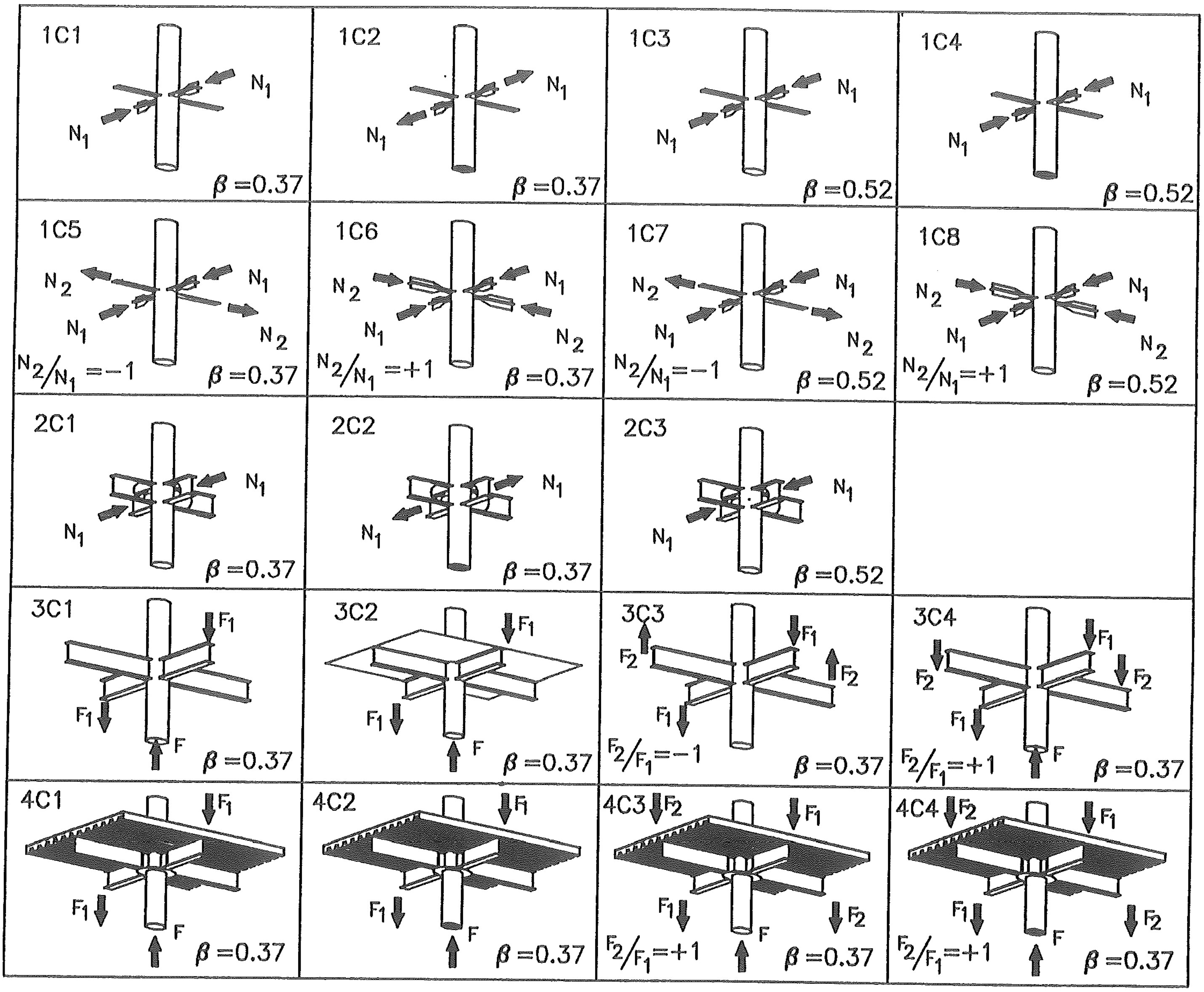
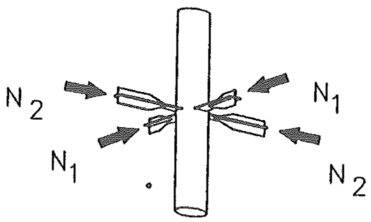
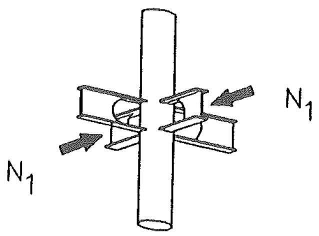



TABLE 1 Overview experimental programme




| TEST | β | Concrete infill in column | $\frac{N_2}{N_1}$ | Compr. or Tens. | $N_u$ $Expt$ [kN] | $\frac{N_{u,num}}{N_{u,expt}}$ |
|---|---|---|---|---|---|---|
| 1C1 | .37 | no | 0 | C | 245.3 | 1.05 |
| 1C2 | .37 | yes | 0 | T | 510.8 | |
| 1C3 | .52 | no | 0 | C | 325.0 | 1.08 |
| 1C4 | .52 | yes | 0 | C | 670.8 | |
| 1C5 | .37 | no | -1 | | 175.6 | 1.08 |
| 1C6 | .37 | no | +1 | | 300.8 | 1.05 |
| 1C7 | .52 | no | -1 | | 220.1 | 1.07 |
| 1C8 | .52 | no | +1 | | 499.9 | 1.00 |
| 2C1 | .37 | no | 0 | C | 350.6 | 1.16 |
| 2C2 | .37 | yes | 0 | T | 971.8 | 1.07 |
| 2C3 | .52 | no | 0 | C | 456.0 | 1.12 |

TABLE 2 Overview experimental and numerical results series 1 and 2.

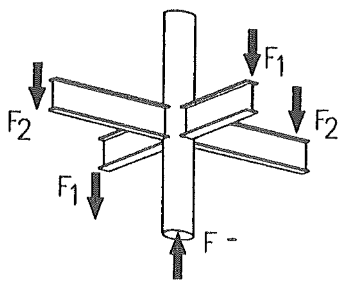
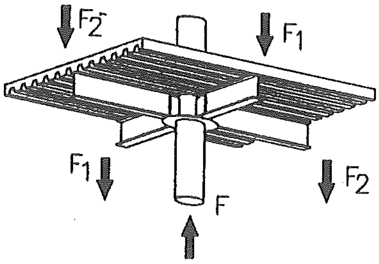
| | TEST | β | Concrete infill in column | $\frac{F_2}{F_1}$ | Steel or Concrete Floor | $M_u$ Expt | $\frac{M_{u,num}}{M_{u,expt}}$ |
|---|---|---|---|---|---|---|---|
| | | | | | | [kNm] | |
|  | 3C1 | .37 | no | 0 | | 82.5 | 0.99 |
| | 3C2 | .37 | no | 0 | S | 87.6 | 0.98 |
| | 3C3 | .37 | no | -1 | | 54.1 | 1.12 |
| | 3C4 | .37 | no | +1 | | 79.0 | 1.01 |
| | | | | | | | |
|  | 4C1 | .37 | no | 0 | C | 162.8 | |
| | 4C2 | .37 | yes | 0 | C | 186.8 | |
| | 4C3 | .37 | no | +1 | C | 117.5 | |
| | 4C4 | .37 | yes | +1 | C | 121.1 | |
| | | | | | | | |

TABLE 3 Overview experimental and numerical results series 3 and 4.