Journal of Constructional Steel Research 114 (2015) 178–187

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Load carrying behaviour of thrust rings for transferring longitudinal pipe forces

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ARTICLE INFO

Article history:
Received 17 December 2014
Received in revised form 27 July 2015
Accepted 29 July 2015
Available online xxxx

Keywords:
Penstock
Pipe
Tests
Concrete
Design model

ABSTRACT

Within a recently finished funded research-project, the load carrying behaviour of thrust rings for the transfer of axial loads from the penstock to the rock was studied.
On the one hand, tests were carried out. Two "full tests", comprising of a pipe with a thrust ring and the surrounding cylindrical concrete block, with two border cases for the slenderness of the rectangular thrust ring (very stocky, very slender) were performed. In addition, 12 plane tests of pipe segments were carried out. The latter ones were carried out, because due to the axial load in the pipe the stresses in the thrust ring along the circumference are constant. Within these tests, the slenderness of the thrust ring, the amount and position of the reinforcement in the concrete and the thickness of the pipe were varied.
Additionally every test was simulated through numerical FEM-calculations. The results of all tests were used to calibrate the accompanying FEM model. Based on all results – tests and FEM-calculations – the fundamentals for a design model were developed.
This paper gives an overview of the project, showing the test setup and the main results. To get realistic FEM-results, the material model for concrete (CDP — Concrete Damaged Plasticity model in ABAQUS) has to be modified. A short overview of the improved parameters is given. Finally the new insights in the load carrying behaviour of thrust rings are shown and the basics for a design model in practice are presented.

1. Introduction

Thrust rings with rectangular cross-sections are mainly used in penstocks to transfer the longitudinal pipe forces via the exterior concrete to the surrounding bed rock (Fig. 1).

They can be seen as a composite component, which transfers very high pipe forces — up to 50,000 kN, because of increasing diameter and pressure in recently erected penstocks.

Surprisingly in relevant design codes for penstocks (e.g. [1–3]) no detailed information is given for the design of thrust rings. In practice simplified models are used, considering the thrust ring as a cantilever (Fig. 1). The maximum force N_{Rd} and also the maximum moment M_r at the thrust ring are depending on the distribution of the concrete pressure σ_c and the maximum concrete stress $\sigma_{c,max}$ at the thrust ring. In practice different assumptions are used with no physical background based on test results. In some cases an additional contact force K at the non-loaded side of the thrust ring is assumed, which reduces the maximum moment M_r (e.g. [4]).

Based on the internal forces M_r and V_r transferred from the thrust ring to the pipe and based on shell theory, the stresses in the relevant sections (so and su in Fig. 1) of the pipe can be calculated.

For usual large penstock diameters (d ~ 3–5 m) the cantilever model for the thrust ring is quite accurate, because the effect of the circular ring plate is negligible. These results are based on 3D-FEM-analyses by the authors for cases in practice.

That means, if the pressure distribution σ_c and the acting contact force K are known for the simple model in Fig. 1 the design of the thrust ring and the pipe are based on the well-known codes for steel design.

This is the reason why, due to limitations of the length of this paper, no more details to the design stresses in the steel parts (thrust ring and pipe) are given.

This paper gives an overview of the investigations carried out in a research project. The load carrying and deformation behaviour of thrust rings are investigated with FEM-analysis as well as laboratory tests at the Laboratory for Structural Engineering (LKI) at the TU Graz.

2. Overview of the research activities

Fig. 2 shows a thrust ring and the principle objectives of the project, which are as follows:

a) Real load carrying capacity of thrust rings (variable N_{Rd} in Fig. 2)
b) Deformation behaviour Δ

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http://dx.doi.org/10.1016/j.jcsr.2015.07.024

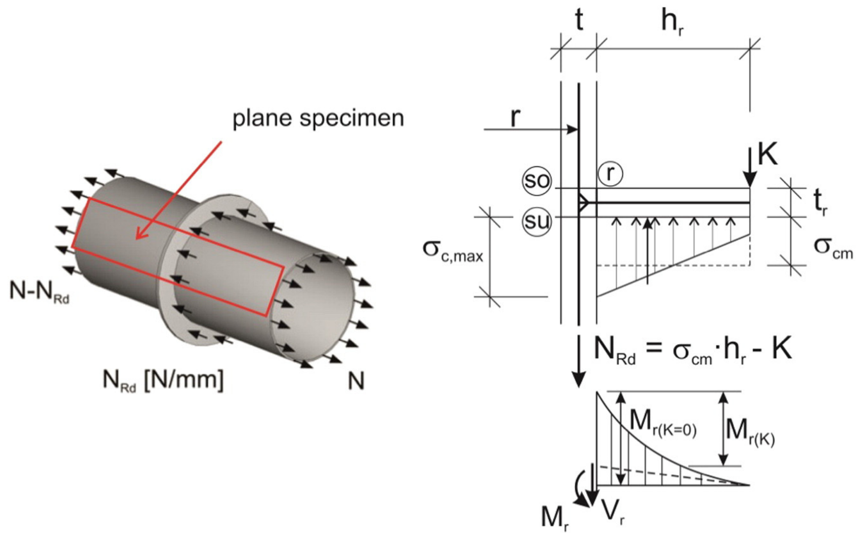

Fig. 1. Overview of pipe and thrust ring and simplified cantilever model.

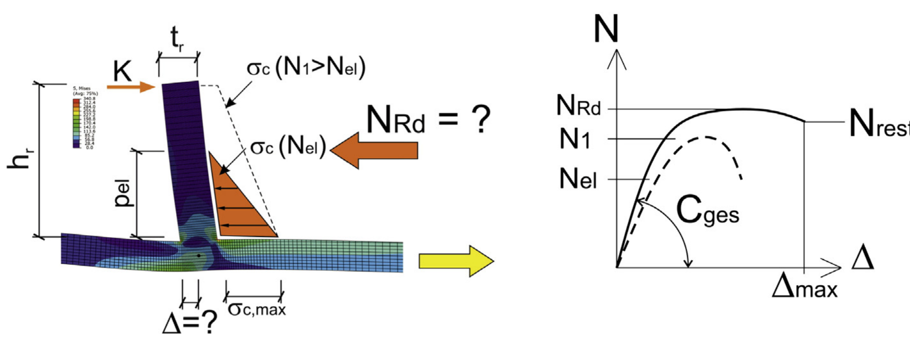

Fig. 2. Principal objectives of the research project.

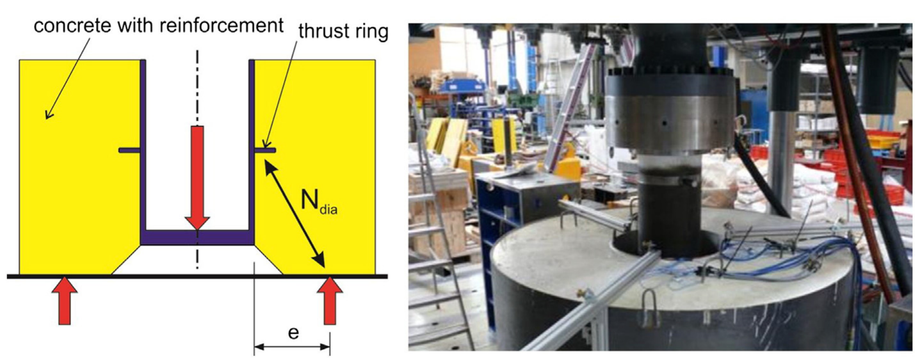

Fig. 3. Graphical presentation of the cylindrical specimen (left); specimen at the Laboratory for Structural Engineering (LKI) at the TU-Graz, $h_r/t_r = 82/8$ (right).

Table 1
Variation of thrust rings (measurements in mm).

Abbreviated designation	Thrust ring h_r/t_r; material	h_r/t_r	Pipe thickness t; material	Concrete
pipe-t10-ring 82/8	82/8 P 460	10	10 P 460	C 20/25
pipe-t20-ring 17/20	17/20 S 355	0.75	20 S 355	C 20/25