Wave Induced Saline Intrusion in Sea Outfalls

Larsen, Torben; Burrows, Richard

Published in:
Proceedings of the 23rd International Association for Hydraulic Research Congress : IAHR

Publication date:
1989

Document Version
Publisher's PDF, also known as Version of record

INTERNATIONAL ASSOCIATION FOR
HYDRAULIC RESEARCH

XXIII CONGRESS

August 21-25, 1989
Ottawa, Canada

WAVE INDUCED SALINE INTRUSION IN SEA OUTFALLS

by

Torben Larsen
University of Aalborg, Sohngaardsholmsvej 57, 9000 Aalborg, Denmark

and

Richard Burrows
University of Liverpool, Brownlow Street, Liverpool L69 3BX, U.K.

Summary

Experimental and numerical studies have shown that the influence of waves increases the tendency of saline intrusion in multi-riser sea outfalls. The flow field in the diffusor under such unsteady and inhomogeneous circumstances is in general very complex, but when sufficient wave energy is dissipated in the diffusor, a well-mixed flow regime occurs where numerical modelling can be applied. The numerical model seems to be able to calculate within a reasonable accuracy, the point where the intrusion begins.

Introduction

The disposal of sewage to the sea through long sea outfalls has been under discussion for more than 25 years. The practice differs significantly from country to country. In U.K. is seen long sea outfalls which discharge untreated sewage several kilometers from the shoreline, whereas the Danish practice is almost the opposite with short outfalls combined with secondary or even better treatment. But despite these discrepancies in environmental aspects, it is a common problem to keep the outfalls in constant function.

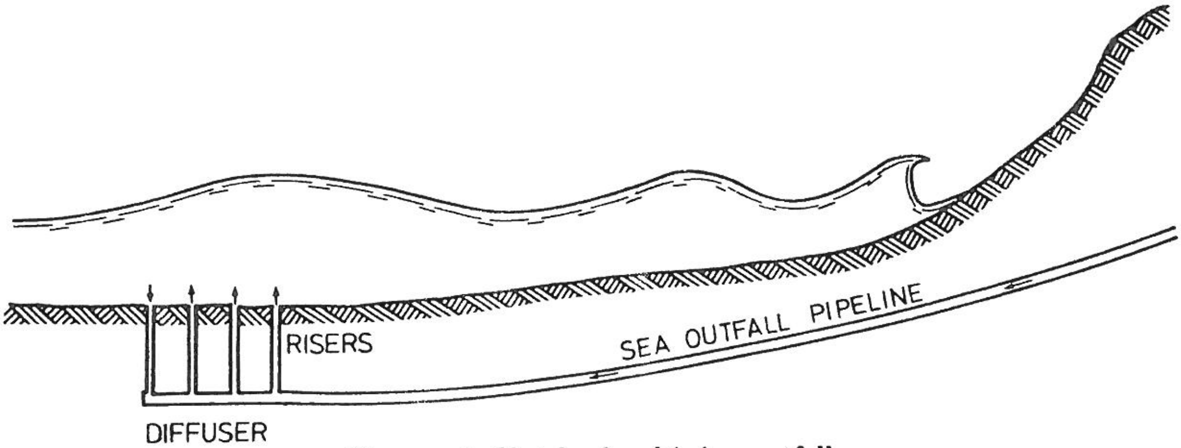

Fig. no. 1: Sketch of multi-riser outfall.

Saline intrusion has been recognized as a serious complication to the hydraulic performance of sea outfalls, Charlton 1985. The intruding sea water is supposed to increase siltation in the diffusor with partial blockage as the further consequence.

The aim of this work is to establish methods and criteria for the determination of the conditions where saline intrusion just starts. The methods presented here should be seen from this point of view more than an attempt to describe all aspects of the extremely complex unsteady and inhomogeneous flow in the purging itself.

Williamson, 1985, has shown that the densimetric Froude.number for an individual diffusor port cannot be used as a criterion for saline exclusion in the steady state situation if earlier operation cycles have permitted saline influx, during shut-down for example. Instead it was suggested that purging could start only when the surplus weight of sea water in the outmost riser is exceeded by the head loss in the other risers. To expand this principle to the unsteady wave situation a numerical model is needed.

It has earlier, Larsen 1986, been reported that wave induced pressure field near the sea bottom can cause backflow through the diffusor ports. In this study the density effect has been added to the numerical model.

Experiments

Physical model tests carried out at the University of Liverpool have been reported in detail earlier, Burrows, R. and Mort, R.B., 1988. The arrangement is shown in Fig. 2.

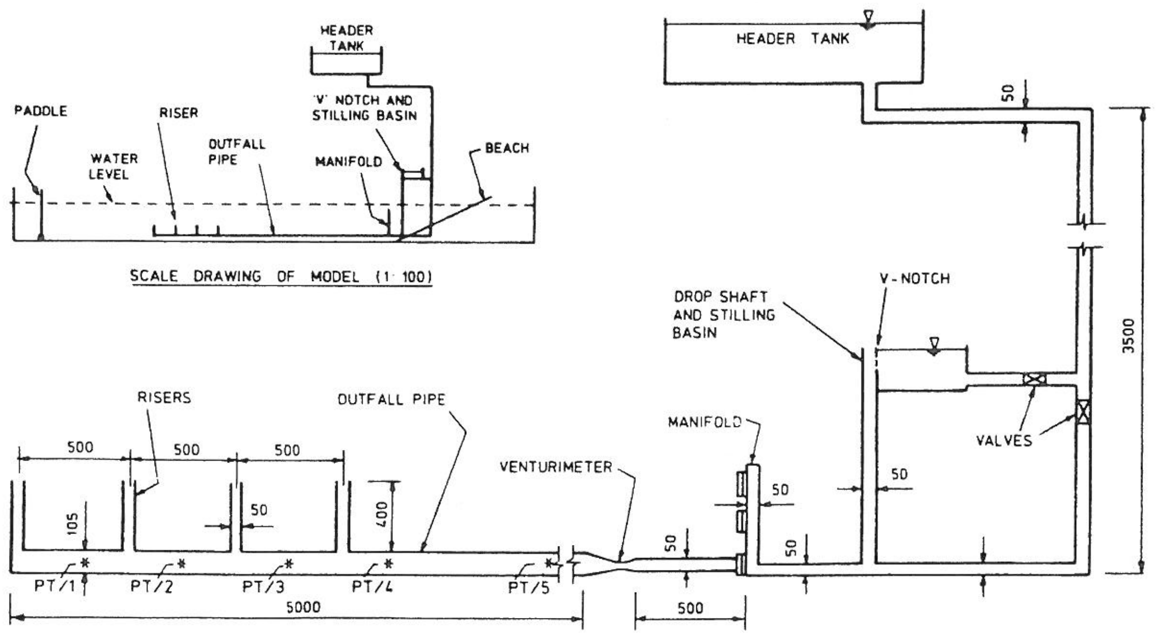

Fig. no. 2: General arrangement of experimental apparatus.

The experiments involve primarily the measurement of the riser velocities and an example is shown in Fig. 3.

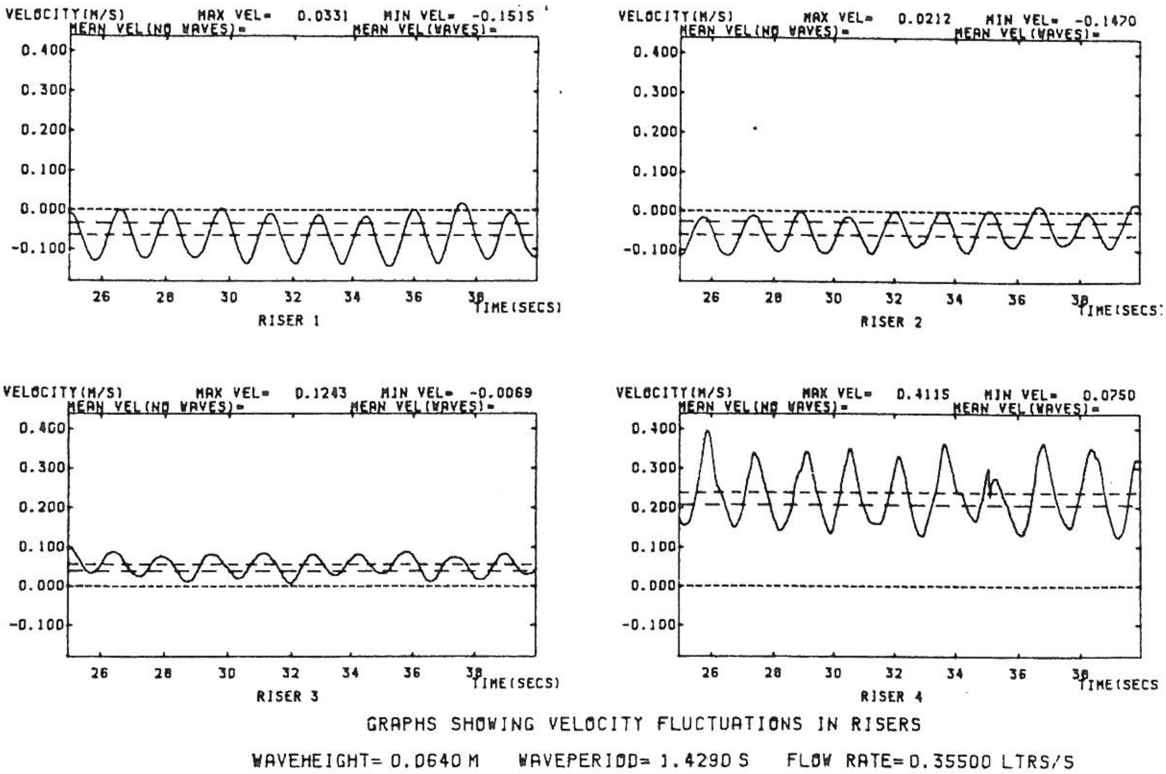

Fig. no. 3: Experimental velocity fluctuations in risers for discharge $Q = 0.35 \cdot 10^{-3} m^3/sec.$

A qualitative but important result of the model tests was the visual observations fo the mixing in the diffusor based on dye injection to the fresh water flow.

In the steady state case without waves, it was typical that a saline wedge was formed in the horizontal diffusor pipe. Even the riser flow showed to be a two "layer" flow when the fresh water flow was low.

In the unsteady case, when the waves exceeded a certain heighth, this picture was totally changed and the flow became almost fully mixed with sea water in one part of the diffusor and fresh water in the other part, separated in a narrow mixing zone near one of the riser tees.

A quantitative experimental description of the transition between the above mentioned characteristic flow regimes is still under investigation and cannot be presented here. Further experiments with varying fresh water flow, wave height, and density difference will be done in 1989 and results will be published later.

Numerical model

To describe the combined effect of waves and density in the well mixed flow regime a numerical model was set up. This model couples a flow model based on the momentum and the continuity equation with a density difference model based on the transport/dispersion equation.

Flow model
The unsteady flow in the diffusor is a very complex phenomenon in general. From a physical analysis of force and energy balances it was concluded that

1. elastic effects of water and pipe could be neglected
2. acceleration terms were more important than friction and density differences
3. density differences did not affect the acceleration but only the pressure.

The momentum equation for each pipe section then becomes:

$$\text{Vertical riser} \quad : \quad \rho A \frac{\partial V}{\partial t} + \rho g A \frac{\partial h}{\partial x} + \tau P + \Delta \rho g A = 0$$
$$\text{Horizontal pipe} \quad : \quad \rho A \frac{\partial V}{\partial t} + \rho g A \frac{\partial h}{\partial x} + \tau P = 0$$

To include the head losses in tees and diffusor ports, the energy equation was applied at those points. The friction in the pipe sections was calculated from the Darcy-Weisbach equation. The gravity term in the riser equation gives the effect of density difference and the coupling to the salt model. Further details are seen in Wylie and Streeter, 1985.

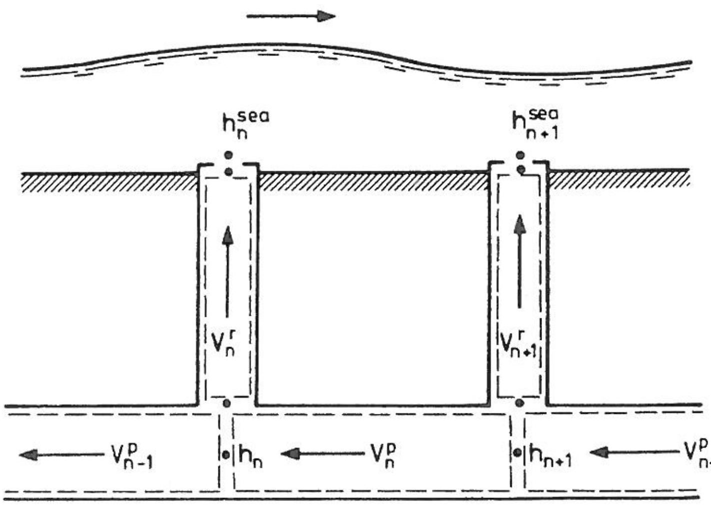

Fig. no. 4: Outline of rigid column flow model.

The unsteady boundary conditions just outside the diffusor port was the wave induced pressure fluctuations, which were calculated from linear wave theory.
The continuity in each tee was

$$Q_{n-1}^{pipe} - Q_n^{pipe} - Q_n^{riser} = 0$$

To solve the equations the momentum equations were substituted into the continuity equations. According to the above mentioned assumption no. 2 all friction and density effect could be taken on the old time step. The substitution then gives a linear equation for each tee in the form

$$A_n h_{n-1} + B_n h_n + C_n h_{n+1} = D_N$$

The simultaneous linear equations were then solved by the double sweep method to give the head on the new time step. Substitung back in the momentum equations then gave the velocities.

Salt model

The salt model was more precisely a mass balance model for the density ρ based on the transport/dispersion equation

$$\frac{\partial \rho}{\partial t} + V \frac{\partial \rho}{\partial t} = D \frac{\partial^2 \rho}{\partial x^2}$$

This model differs significantly from the flow model because it needs much shorter Δx to avoid numerical dispersion.

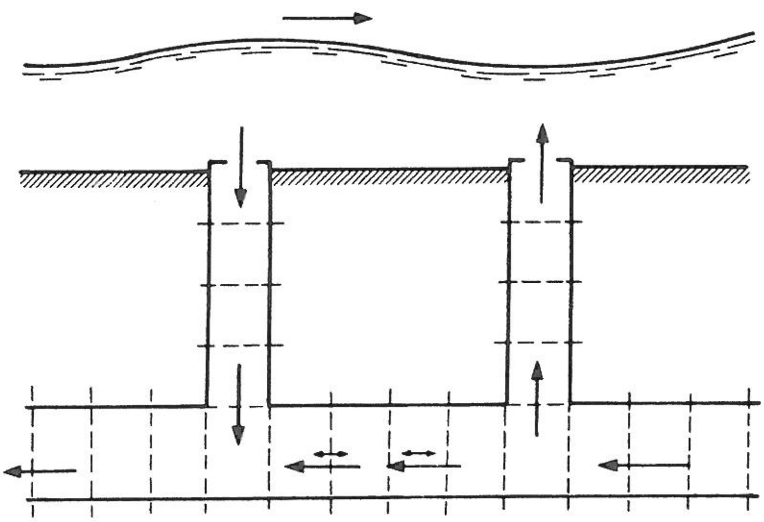

Fig. no. 5: Outline of transport/dispersion model

The finite difference solution of transport/dispersion is well-known and details will not be given here.

For numerical reasons a standard steady state dispersion coefficient for turbulent pipeflow was applied. As mentioned later the value of this parameter is unimportant.

Results from numerical model

All the results presented here refer to geometry, flow and wave situations equivalent to the model test described earlier. Only a few principal results will be shown.

Fig. no. 6 shows the velocities in the riser with no basic flow where the diffusor contains sea water only.

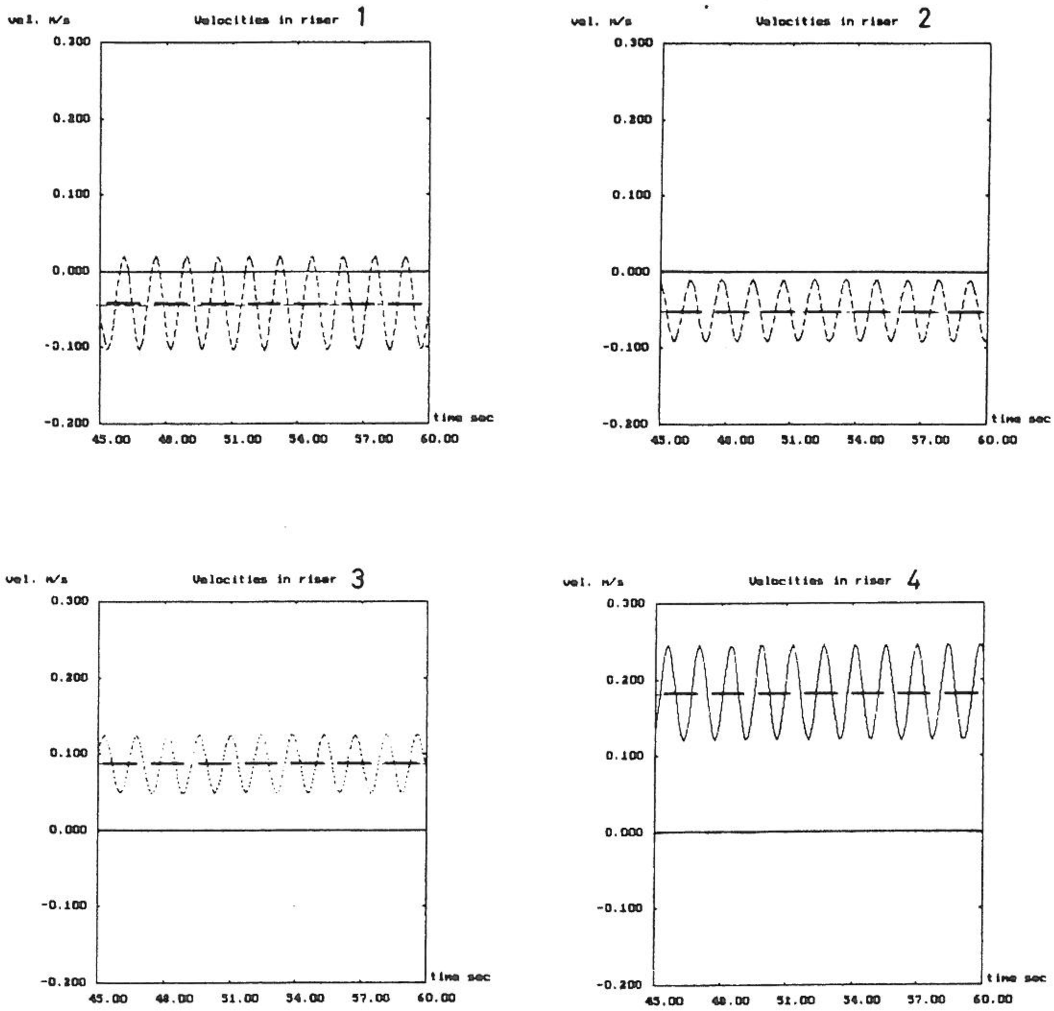

Fig. no. 6: Computed riser velocities equivalent to Fig. no. 3.

Fig. no. 7 shows the computed density distribution in the diffusor pipeline with a basic flow of $Q_o = 0.00035\ m^3/sec$, which shows a typical situation with saline intrusion in the diffusor. It is seen how the mixing takes in a narrow area between two tees in agreement with the observations in the model tests. The presence of this mixing area is the result of the oscillating flow, which indicates that most of the buoyancy energy is dissipated here.

Figure no. 7 shows the longitudinal density distribution along the diffusor pipe equivalent to Figure no. 6 and the steep gradient indicates the mixing area.

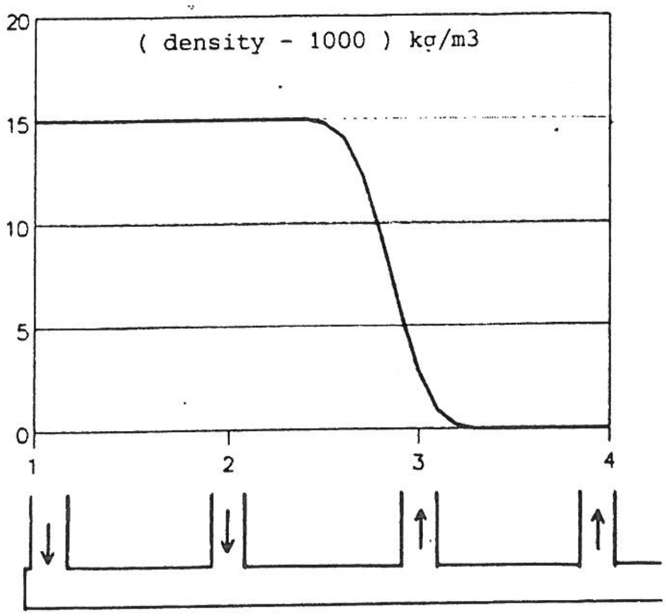

Fig. no. 7: Longitudinal density distribution in diffusor pipe equivalent to Fig. no. 6.

Conclusions

1. Experiments and computations show that waves and density differences will induce unsteady internal flow in the diffusor and a net circulation will occur where sea water will purge into the outermost ports and out of the innermost.

2. The input of buoyant energy from the sewage discharge strongly increases the tendency for purging of sea water through the outermost ports. The numerical model seems to agree acceptably to the experiments.

3. Despite several simplifications, the numerical model seems to be a reasonable tool for the determination of the point where saline intrusion begins, even in the non-wave case.

Acknowledgement

The authors wish to record their appreciation of the Commission of the European Community for providing the financial support for this research co-operation between the Universities of Liverpool and Aalborg through Stimulation Action Contract ST20046S.

References

Burrows, R. and Mort, R.B. "Wave Action on Multi-Riser Marine Outfalls" to be presented at the IAHR "Second Water Modelling and Measurement" Conference in Harrogate, U.K. April 1989 (postponed from Nov. 1988).

Charlton, J.A. "Sea Outfalls". Developments in Hydraulic Engineering" edited by P. Novak, Elsevier, Amsterdam, 1985.

Larsen, T. "The influence of waves on the hydraulics of sea outfalls". Proc. 20th ASCE International Conference on Coastal Engineering, Taiwan, Nov. 1966.

Williamson, D.L. "Seawater circulation in sewage outfall tunnels". Journal of Hydraulic Engineering, ASCE, Vol. 111, No. 5, May 1985.

Wylie, E.B. and Streeter, V.L. "Fluid Transients". FEB Press, Ann Arbour, Michigan, 1985.