

Numerical Model of Sediment Transport in Free Surface Flow

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Abstract

A 3D numerical model for simulation of free surface flow and sediment transport with sand bed deformation is presented in this study. The flow solver is based on the Finite Volume VOF solver *navalFoam*, which is a part of *Naval Hydro pack*. The sediment module incorporates suspended load and bed-load transport, with sand bed elevation evaluated using the Exner equation. Deformation of sand bed due to sediment deposition and scour is performed by the automatic mesh motion solver. Validation of the model is carried out on two test cases.

1. Introduction

Simulation of flow and sediment transport in channels, rivers and shallow seas is a challenging, but important problem due to the impact of sediment erosion and deposition on river beds, sea beds and marine objects. Coupling between the fluid flow and sediment transport is required in order to achieve satisfying results. This includes accurate predictions of the flow and free surface waves, realistic shear stress values, correct suspended and bed-load sediment transport calculations with stable bed motion capabilities.

2. Mathematical Model

Suspended load transport of sediment is modelled by the convection-diffusion equation:

$$\frac{\partial c}{\partial t} + \nabla \cdot \left(\mathbf{U} - v_s \frac{\mathbf{g}}{|\mathbf{g}|} \right) c = \nabla \cdot (\nu_t \nabla c), \quad (1)$$

where c is the sediment concentration, v_s is the sediment fall velocity and ν_t is sediment diffusivity. Bed-load transport is modelled by an explicit expression and discretised using the Finite Area Method (FAM):

$$\mathbf{q}_b = q_0 \frac{\boldsymbol{\tau}_b}{|\boldsymbol{\tau}_b|} - C |q_0| \cdot \nabla_s \eta, \quad (2)$$

where $\boldsymbol{\tau}_b$ is the bed shear stress vector, C is a constant (1.5 - 2.3), ∇_s is a surface gradient and η is bed elevation.

Bed elevation η is evaluated using the Exner equation, discretised by FAM:

$$\frac{\partial \eta}{\partial t} = \frac{1}{1-n} [\nabla \cdot \mathbf{q}_b + D - E] \quad (3)$$

Bed-load transport vector is directly coupled with the Exner equation.

3. Numerical Procedure

1. Solve the fluid flow equations (pressure, velocities, phase volume fraction, turbulence)
2. Calculate suspended sediment transport
3. Calculate surface bed-load transport flux and solve the Exner equation
4. Execute mesh motion to account for elevation

4. Validation

4.1 Channel with Net Deposition of Suspended Load and a Fixed Bed

The test case consists of a straight channel with perforated bottom, such that only sediment deposition is possible and no entrainment from the bed occurs, Fig. 1. Concentration measurements by Wang and Ribberink (1986) are used for validation of suspended sediment transport. Experiment reaches equilibrium conditions and is considered steady-state. Fig. 2 shows the comparison between calculated and measured suspended sediment concentration profiles at various sections.

Figure 1: Experimental set-up for a perforated channel

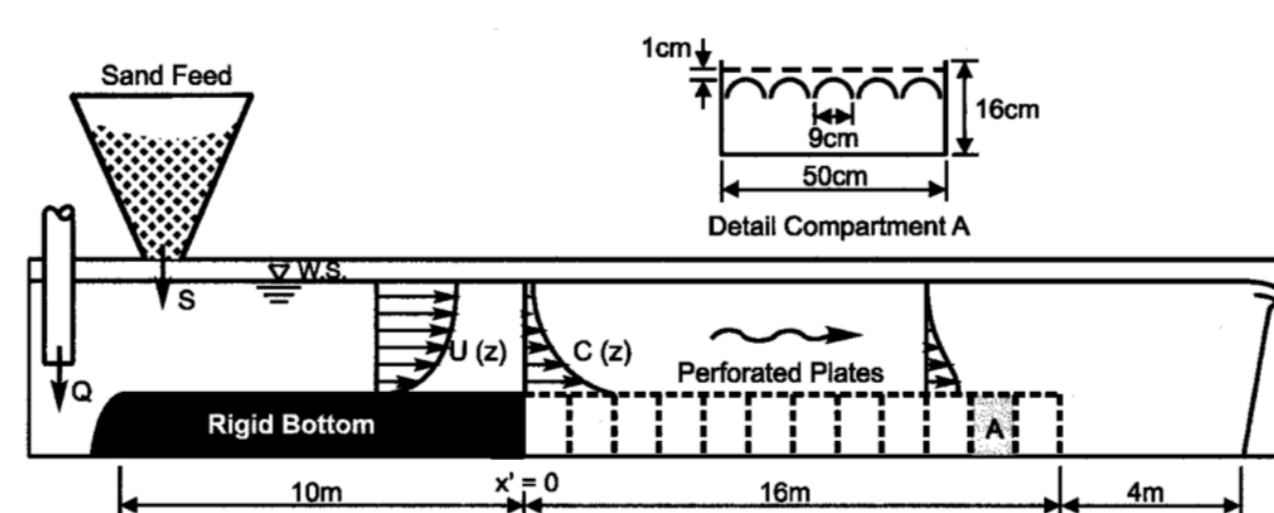
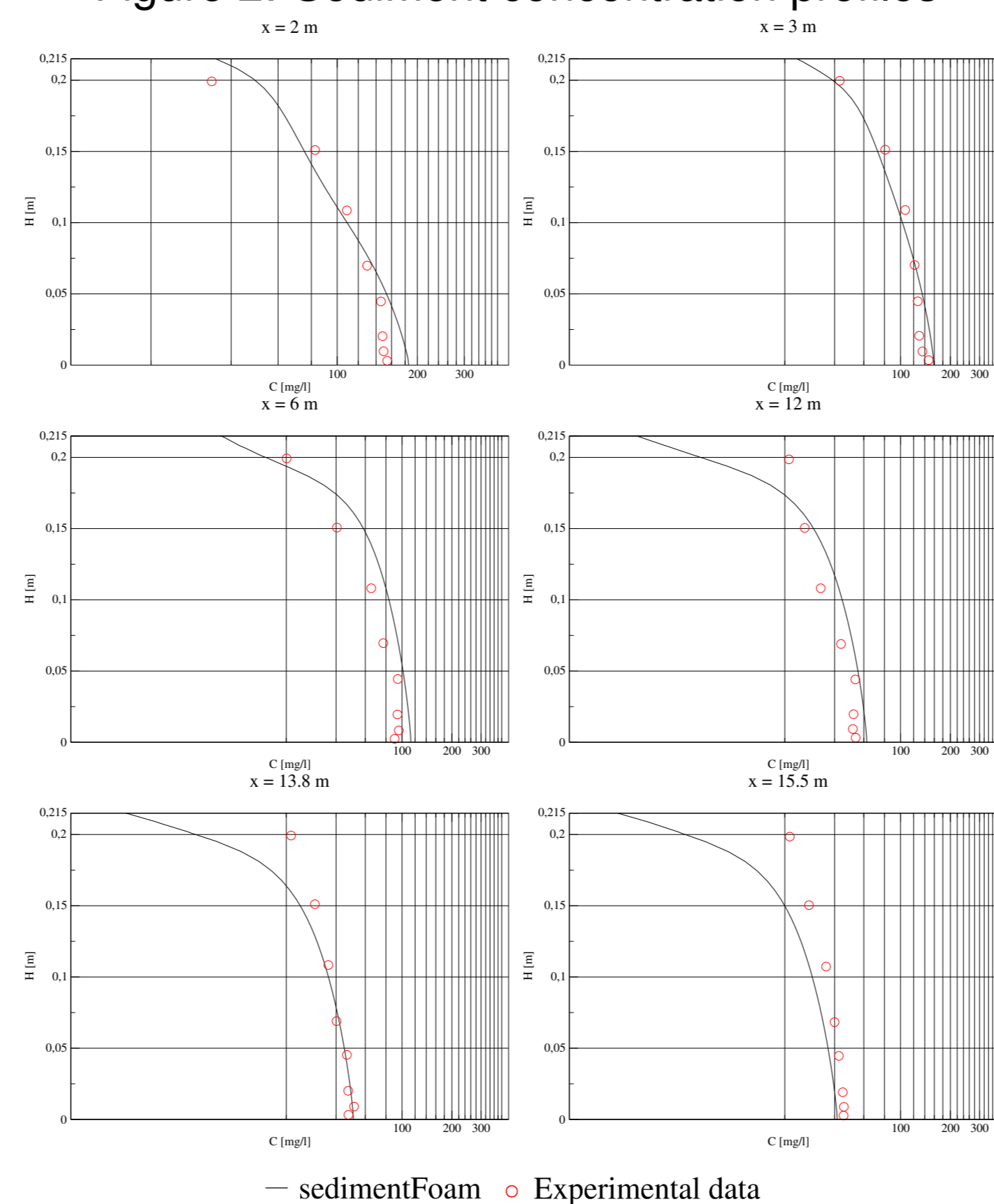
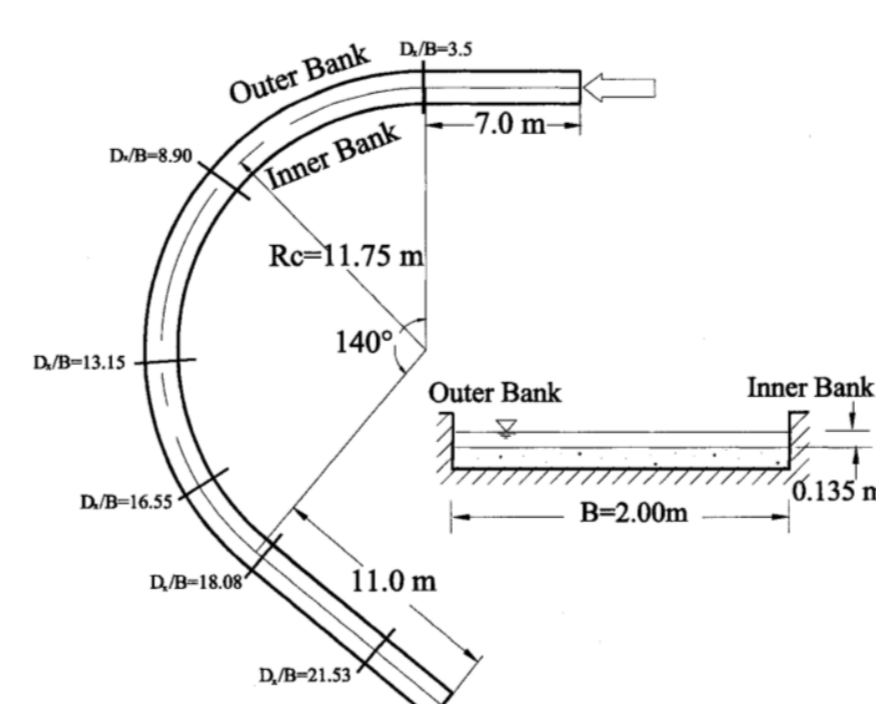


Figure 2: Sediment concentration profiles



4.2 Flow and Sediment Transport in a 140° Channel With a Mobile Bed

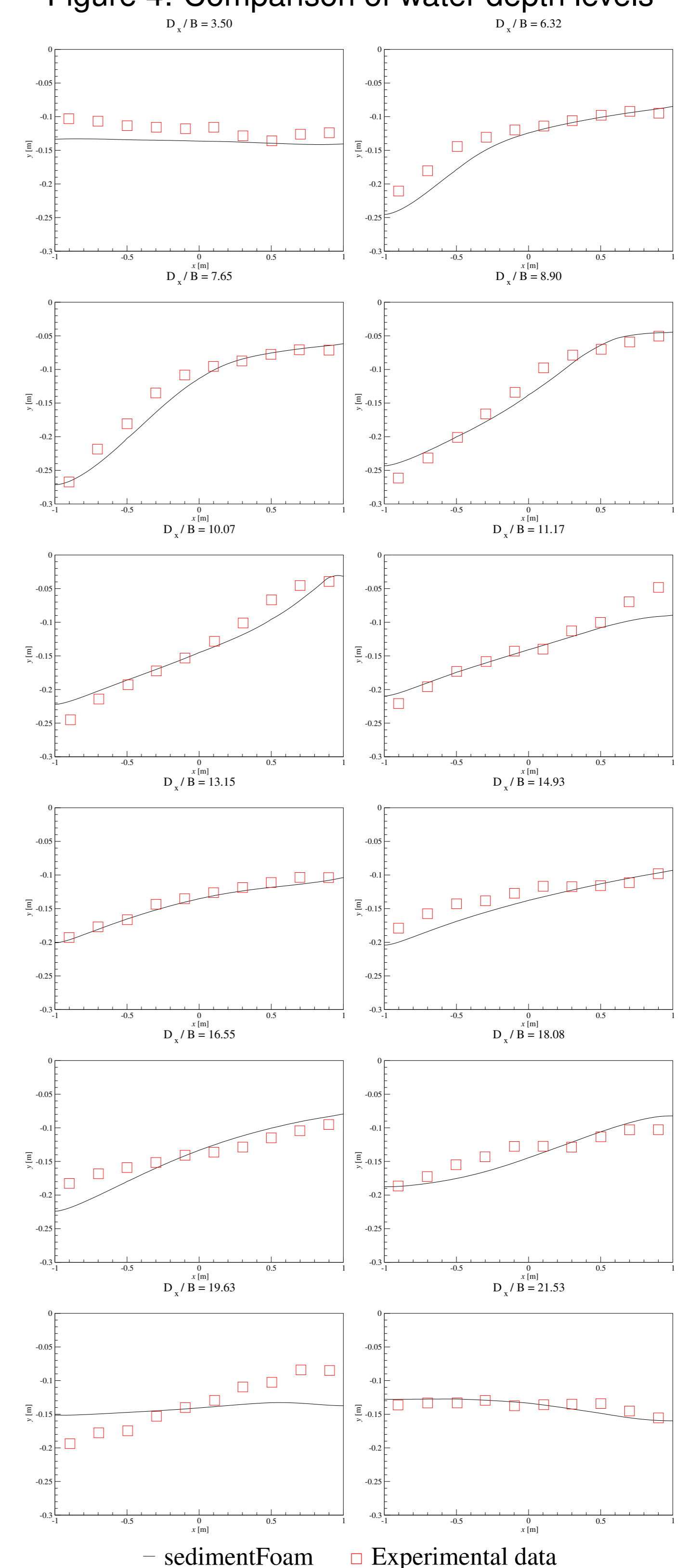
Figure 3: Experimental set-up for a curved channel



Flow and sediment transport in a 140° channel is simulated. The channel, Fig. 3, is covered with

a 30 cm sand layer, where suspended transport, bed-load transport and bed deformation occur simultaneously. Bed depth measurements performed by Olesen (1985) are used for validation. The case is considered steady-state, since the experiment reaches equilibrium conditions. Fig. 4 shows the comparison between the simulated and measured water depth levels at various sections of the curved channel.

Figure 4: Comparison of water depth levels



5. Conclusion

Results from the suspended transport test case, Fig. 2, are in very good agreement with experimental data, especially near the bed. Curved channel results, Fig. 4, show excellent agreement with the experimental data in most sections, which can be improved with a better definition of inlet and outlet boundary conditions.

Overall, results are considered satisfactory and the numerical model is considered validated.