Text Marco van Dijk
University of Pretoria
mvd@sinotechcc.co.za

Fanie van Vuuren
University of Pretoria
fvuuren@eng.up.ac.za

Physical modelling to solve 3D flow problems

DURING AUGUST 2006 floods devastated the coastal town of Glentana, 35 km east of Mosselbay and 20 km south-west of George. At the end of July and the beginning of August 2006 continuous rain had saturated the catchment areas in the southern Cape. On 2 August 2006 the rainfall intensity increased resulting in an increase in peak flows equal to the 1:18 year storm events. The major storm water infrastructure was unable to cope with the increased flow and one section of the storm water infrastructure, which had to transfer the runoff upstream from the caravan park through the road fill, was insufficient and extensive damming occurred that inundated the caravan park. Failure of the structures occurred quickly due to the cohensionless material supporting the structures. MVD Consulting Engineers (South Cape) (Pty) Ltd were appointed to analyse and design the entire storm water system and it was apparent from the start that there were areas with complex three-dimensional flows. It was subsequently decided to evaluate the stormwater components by means of hydrological and hydraulic modelling and to construct physical models for the intricate sections. Sinotech CC was subcontracted by MVD to perform the physical modelling.

The Glentana storm water system consists of three contributing runoff areas which are diagrammatically illustrated in figure 1. A schematic layout is given in figure 2.

Two areas where there were excessive damage were just downstream of the main road on the Hoogekraal system (point A) (figure 3) and the area where all three run-off areas join at the restaurant (point B) (figure 4).

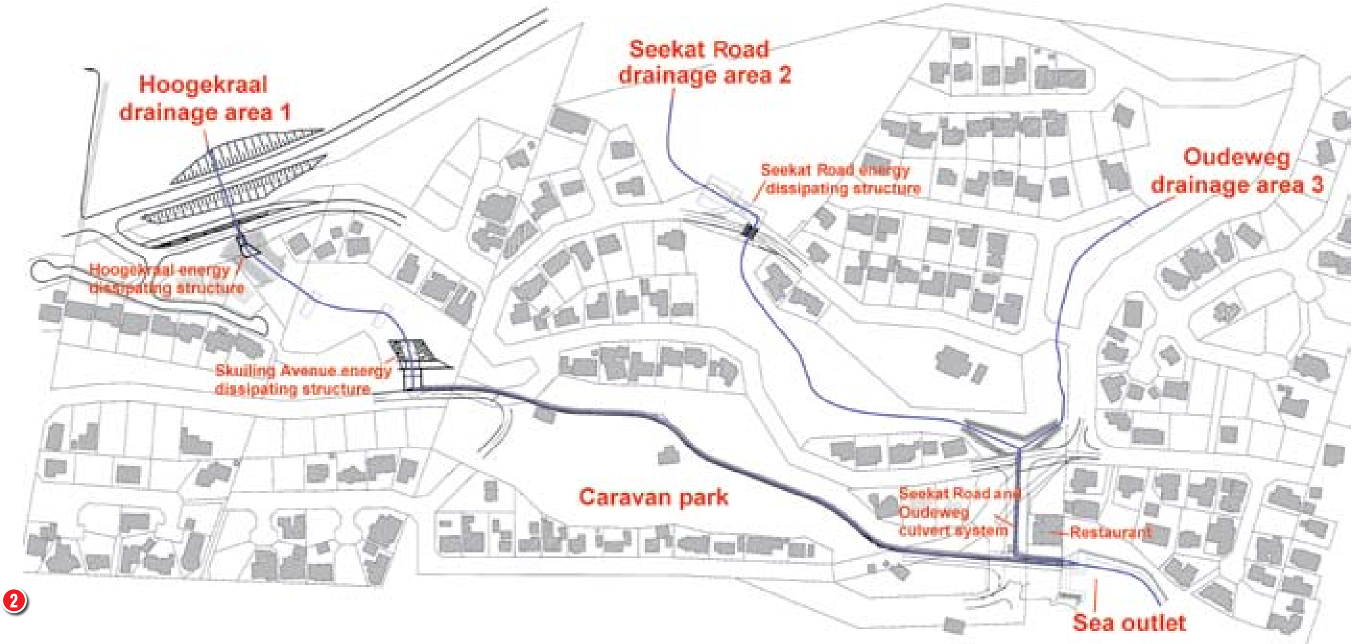
The two physical model studies that have been completed are referred to as the Hoogekraal energy dissipating structure model (point A) and the Seekat Road and Oudeweg culvert system model (point B), shown in figure 1.

PHYSICAL MODELLING

The stormwater upgrade and reinstatement and improvements of the available infrastructure entailed a number of structures where the flow direction will have to change and where excessive energy needs to be dissipated. The flow regime in the rivers tends to be supercritical which required special assessment of the system components.

Appropriate uniformities for model studies include the Froude number, Reynolds number and the Weber number. Experience [1 & 2] has indicated that Froude uniformity can be used to investigate

Figure 1 System layout
Figure 2 Schematic layout
Figure 3 Hoogekraal twin pipe culvert system failure
Figure 4 Confluence of three run-off regions (restaurant area)
Figure 5 Pressurised flow (2 x 1,2 m diameter concrete pipes) (photo courtesy of T Barnard)
Figure 6 Opened joint in pipe culvert



surface vortices, if the Weber number is in excess of 120 and the Radial Reynolds number is greater than 3 x 10^4. In the models the values of the Weber number and Radial Reynolds number are more than the suggested criteria and hence Froude uniformity was used in the models.

The objective of any model study is to ensure that the model accurately represents the behaviour of the prototype. This requires that amongst other similarities, the flow regime behaviour should be represented by the flow in the model. While varying the geometric parameters by the same scale factor, the hydraulic values have to be converted by the appropriate dimensionless parameters. The driving force in any free surface model is gravitation using Froude uniformity, which represents the ratio of inertial and gravitational forces.

MODELLING OF THE HOOGEKRAAL ENERGY DISSIPATING STRUCTURE

It is believed that piping was the reason why the storm water system failed at Hoogekraal. The system was flowing under pressurised flow conditions as shown in figure 5 and water was forced through the joints (figure 6) liquefying the supporting soil and created piping which eroded the surrounding material. The stormwater pipe segments were washed out from the downstream side.

A storm water system was designed for Hoogekraal. The new design incorporates an internal HDPE liner which will be installed in the reinstated two storm water pipes permitting pressurised flow with the 21,5 m high energy dissipating structure at the outlet to dissipate the energy and direct the water (figure 7). The design flow capacities for the Hoogekraal energy dissipating structure was determined as Q_{50} = 16,9 m³/s and Q_{100} = 22,9 m³/s from a hydrological analysis of the catchment area. Froude uniformity requires that the Froude numbers in prototype and model must be equal, hence:

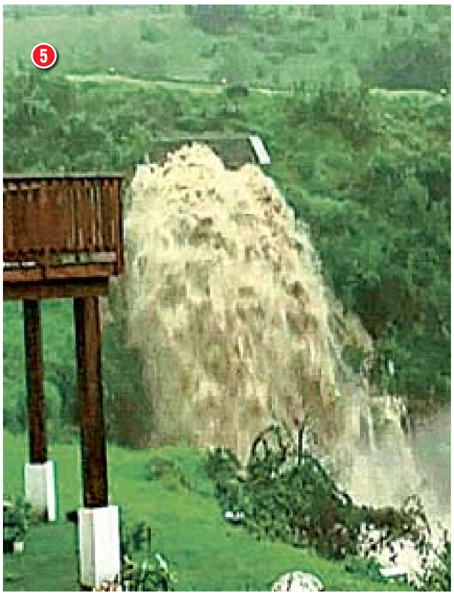
$$Fr_{Prototype} = Fr_{Model}$$

$$\frac{V_{Prototype}}{\sqrt{gD}_{Prototype}} = \frac{V_{Model}}{\sqrt{gD}_{Model}}$$

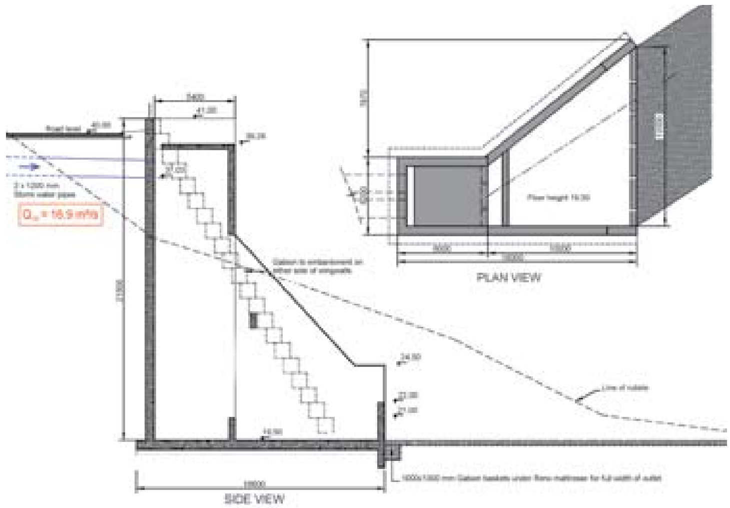
A scale of 1:24,8 was selected for the modelling of the Hoogekraal energy dissipating structure. From the assumed Froude uniformity the other scale relationships could be determined. The 1:50 and 1:100 year model flow rates were determined as 5,53 ℓ/s and 7,49 ℓ/s respectively.

The observations that were made of the preliminary designed layout reflected the following:

- At low flows the water will drop onto the floor slab just upstream from the second wall, that is, missing the baffle wall and designed plunge pool (figure 8)
- At high flow rates most of the flow is streamlined along the right wall with the creation of a backflow on the left side of the structure



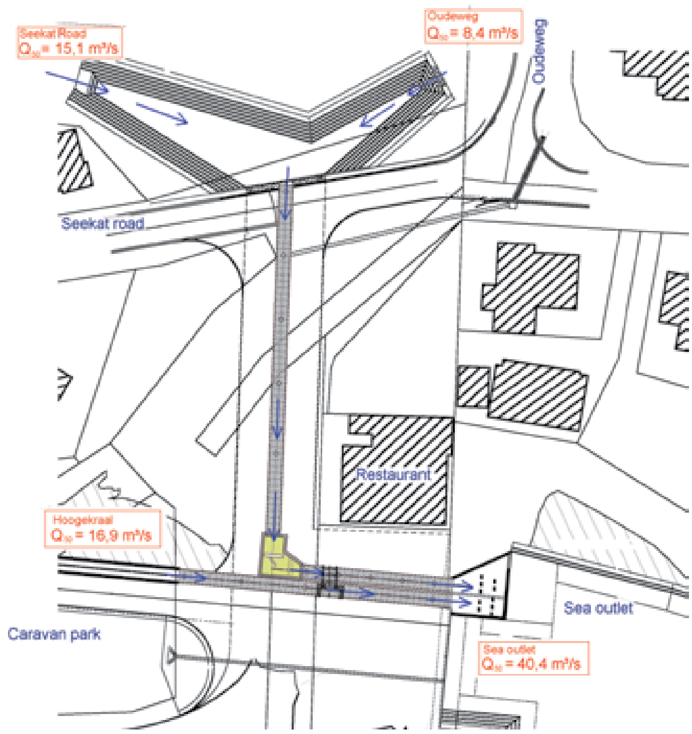
7



8

9

10



The model study highlighted the importance of providing sufficient aeration at the top of the structure especially during the high flow rates and to create resistance downstream for the deflection of flow across the downstream natural channel. This was accomplished by introducing the following alterations:

- The angle of the left wall relative to the structure was changed, and
- The end wall was raised

MODELLING OF THE SEEKAT ROAD AND OUDEWEG CULVERT SYSTEM

The Seekat Road and Oudeweg culvert system is a large complex system. The Seekat Road and Oudeweg run-off areas join just upstream of Seekat Road from where the flow have to be transported in a 2,4 m x 2,4 m culvert underneath the road and parking area, turning just after the restaurant through ninety degrees (left) towards the sea channel (figures 2 and 10). At the sea energy dissipating structure the run-off from the Hoogekraal area flowing through a 2,4 m x 2,4 m culvert merges with the flow from the Seekat Road and Oudeweg run-off areas.

The flow path between Seekat Road and the position where the flow direction needs to be changed is steep, resulting in water flowing supercritical (Fr > 1). One option was to install two 2,4 m x 2,4 m culverts in parallel at lesser slopes between the confluence of the Seekat Road and Oudeweg run-off areas to the Restaurant where the direction of flow needs to be changed. The flow regime could be sub-critical and that the positional energy could have been dissipated through a vertical drop and energy dissipating structure at the end of the culvert section. This would have required excessive backfill as well as the additional culvert segments.

The alternative, which was adopted, was to utilize the current slope which will result in supercritical flow and require only a single 2,4 m x 2,4 m culvert. An energy dissipating structure was then designed at the Restaurant to create a hydraulic jump which facilitates the ninety degree directional change. The section downstream from the energy dissipater at the Restaurant to the energy dissipation structure at the end of the system (Sea outlet) will flow supercritical. At the Sea outlet energy dissipater, the culvert system combines the flow with that from the Hoogekraal system, and this energy dissipating structure was designed to accommodate this total flow and release it into the sea.

The scales were selected as 1/20 for an undistorted Froude uniformity model, adhering to the criteria that the influence of surface tension and laminar flow could be discarded.

Figure 11 reflects a general layout of the Seekat Road and Oudeweg culvert system while figures 12 and 13 provide a close-up view of the two components.

The model indicated high turbulence at the entrance to the downstream culvert, reducing the capacity to below the required 1:50 year flow rate and that the circulation in the structure could be reduced by the change in the width of the structure. The optimum width was obtained as well as improving the inlet conditions by the provision of a deflector beam.

Figure 14 reflect the final layout of the structure which proofed that the 1:50 year flood could be accommodated in the system and that the energy sufficiently dissipated at the sea outlet structure to have minimal effect on the sea channel stability.

SUMMARY

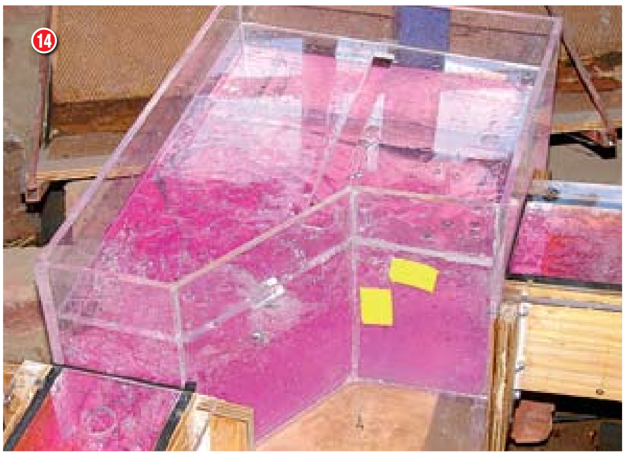
Physical modelling of the Glentana stormwater system confirmed the value of modelling to optimised dimensional layout and provides confirmation of functional capacity to handle the flow rate. The modelling also provides valuable insight into the behaviour of the flow through the storm water network and highlighted the potential problem areas.

References

1 Nakato, T and Krutten, M 1999. *Coping with strong cross flows at pump intakes*. Procceedings of the XXVIII IAHR Congress: Sustainable Water Resources Management at the Turn of the Millennium, Graz, Austria, 22–27 August (Reprint 1398).

2 Hecker, G E 1984. *Scale effects in modeling vortices*. Symposium on Scale Effects in Modeling Hydraulic Structures, International Association for Hydraulic Research. □

▶ **Figure 7** Hoogekraal energy dissipating structure (intermediate layout)
Figure 8 Side view of the trajectory of the flow stream
Figure 9 Side view of the model at high flow rates (Q_{100})
Figure 10 Seekat Road and Oudeweg culvert system
Figure 11 General view of the layout of the Seekat Road and Oudeweg culvert system
Figure 12 Side view of the restaurant energy dissipation structure
Figure 13 Downstream view of the sea energy dissipation structure
Figure 14 Final layout of restaurant energy dissipating structure



Source:
http://www.saice.org.za/downloads/monthly_publications/2007/CivilEngJune2007press/#/0