Rijnmond tidal model control system

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SUMMARY

This paper is a description of the control of the "Rijnmond Model" developed for the Delft Hydraulics Laboratory. The model is a large tidal/salinity model of the Rotterdam Waterway estuary and portions of the North Sea. New control equipment and the R.M.C.S. (Rijnmond Model Control System) software is used for control of the model. This paper reviews the design, the implementation and experience with the system.

1. INTRODUCTION

The Delft Hydraulics Laboratory in The Netherlands is an institute for applied and fundamental scientific research in the fields of hydraulics, hydrodynamics, and hydrology. The Laboratory uses both physical and mathematical models in its investigations.

The Rijnmond Tidal Model, a physical scale model of a section of the North Sea, the Rotterdam Waterway Estuary and branches of the river Rhine, was originally used to provide information and guidance during the building of the Europoort, one of the world's largest shipping ports, and the Maasvlakte, the artificially made land fill at the mouth of the river. See fig. 1 for an over-
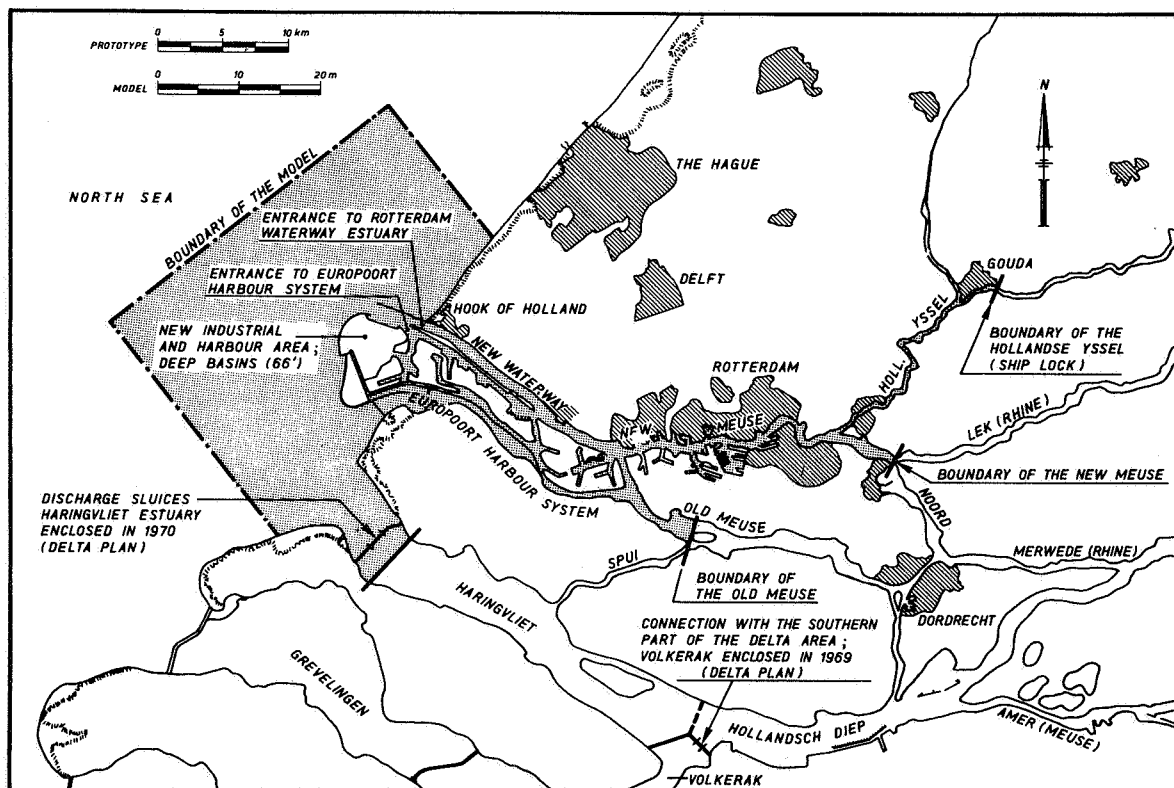

Fig. 1. Plan of the model area

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view of the geographical area involved. The water area included in the model is shown in gray.

The model dates from 1965. The main purpose of the experiments at that time was to determine the influence on the flow patterns in the Rijnmond area. These studies made it possible, for example, to minimize the side forces on ships entering and leaving the waterway. The scope of the investigations has steadily broadened and at present includes studies in general water management, water quality control, water pollution, salt water intrusion, and disaster control.

The scales of the model are :

horizontal 1 : 640
vertical 1 : 64
time 1 : 80

This means that the model area is approximately 40 meters by 50 meters and that a normal tidal period of 25 hours is realized in 18 minutes and 45 seconds. See fig. 2 for an inside view of the model showing the mouth of the river and the Maasvlakte as seen from the North Sea side.

At its inception in 1965, the technology and the main purpose of the model was very much different from the situation in 1976. The control boundaries at the seaside for simulation of the tidal movement were constructed as overcrested weirs. The waterflow then was varied in time by feedback control on the water velocities along the boundaries or on the posi-

tions of the weirs. The desired programs were created on specially made analog programmers and the model was trimmed by a trial-and-error method. Because of lack of enough well-known boundary conditions and because of much interaction between the different weirs, it was a very difficult job to create a new tidal situation in the model. In the light of these experiences and because of the goals that had to be met for future research in the model, a very thorough and extensive study was performed in order to be sure that the new objectives could be met.

New technology for programming (digital computers) and better measuring systems were now available, and with the aid of mathematical models, a new control philosophy was developed. A new control system was designed and the software house, PANDATA, was given responsibility for the development of the software called the Rijnmond Model Control System (RMCS). The RMCS control system runs concurrently with a data acquisition system on a PDP computer. Both systems form the total software complex of the model; RMCS controls all hardware and the data acquisition system samples data from instruments for further analysis and interpretation according to the purpose of the experiment. We will, in this paper, deal only with RMCS, the control system.

Throughout this paper we will be using the term "tide". In the context of the control philosophy, a tide is essen-
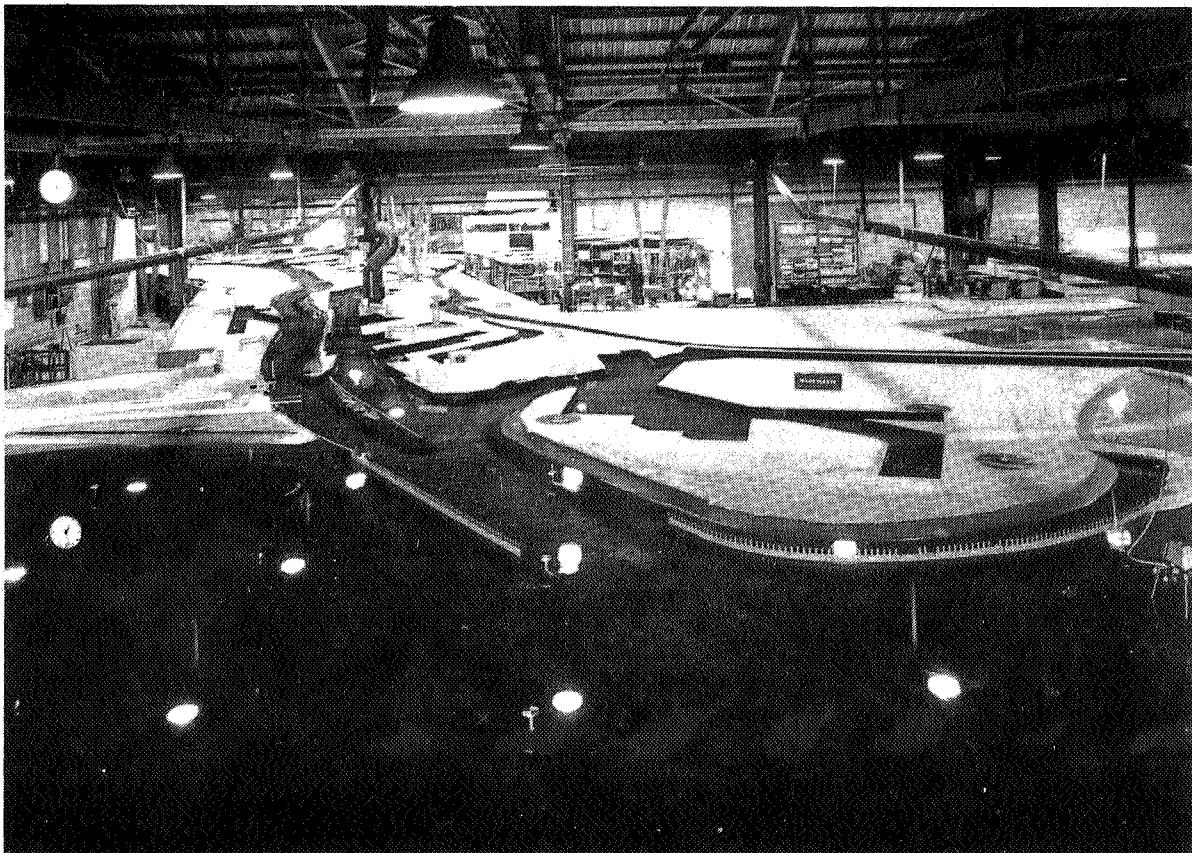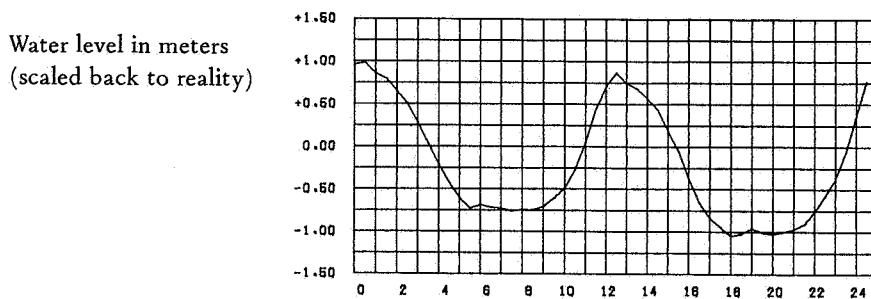

Fig. 2. Inside view of model.

Water level in meters
(scaled back to reality)

Fig. 3. Time in hours (scaled back to reality)
A common water-level curve at Hook of Holland.

tially defined by the water-level at a measuring loca-
tion in the center of the model. This water-level closely
resembles scaled actual measurements taken in the
North Sea. Accurately simulating the scaled North
Sea water-level curve is the primary goal of the con-
trol system and is necessary before any experiments
with a tide can begin. A small number of North Sea
water-levels and velocity measurements are available
for each tide to be generated. All measured data are fed
into a mathematical model which computes the first
approximation values of the control functions in terms
of Fourier components. Starting with these initial
values a period of adjustment is necessary before a
tide acceptably simulates reality. Water-level curves
and water-currents realized in the model have to be
accurate and in reasonable agreement with reality,
particularly the central water-level at Hook of
Holland.
Fig. 3 is an example of a common water-level curve
over the standard tidal period. On the horizontal axis
the hours are shown in model time 0 till 25 hours
which takes 18 minutes and 45 seconds to simulate.
At the vertical axis the water-level is shown in meters
relative to the standard Dutch reference water-level
called N.A.P. This gives a difference between high and
low tide in the model of approximately 30 millimeters.

2. PURPOSE OF THE MODEL CONTROL

The purpose of the Model Control is to accurately
generate tides in the model to enable the execution
of experiments under strictly defined conditions.
Taking into account the deficiencies of the original
model control, four important areas of improvement
were identified :
- faster adjustments, preferably automated as much
  as possible;
- better operational control, ease of use and flexibility;
- reproducibility of tides without a need to readjust,
  a library of tides;
- improvement of accuracy.

The adjustment process should be no longer a trial-
and-error method but powerful and flexible methods
should enable the operators to perform adjustment of
new tides. The adjustments necessary to make the
actual model water-level closely match the desired

water-level should be speeded up and automated as
far as possible.
Other desired improvements were easier and better
operational control, better insight into the control
process by means of archival and inquiry possibilities,
automated reporting and error logging. Further, digital
control with the ability to store the control functions
of a specific tide and reproduce them on request with-
out the need for a new adjustment process was a very
important requirement in the development of the con-
trol system.
Also, it was desired that a library of tides be built
allowing immediate simulation of any tide. Although
the accuracy of the replaced system was acceptable,
higher accuracy was preferred with the new control
system. Finally, the design and implementation of the
system had to allow the system to be flexible and ex-
pandable, for example, for other control algorithms
and for multiple day tides.
It was in the light of these goals that new control
equipment and the RMCS software was developed
and installed.

3. HARDWARE

The model is controlled by a PDP 11/40 running under
the RSX-11D operating system. The total hardware
configuration is shown in fig. 4. The model computer
is connected to a central computer facility in another
building. In this remote facility data analysis and data
plotting takes place after experiments are run. Also
located at this remote site is the system terminal used
for overall control of the model computer.
Communication between the process control and data
collection equipment of the model is performed by
'UDC' hardware (standard process control hardware
for PDP's) and a separate analog/digital controller.
The analog/digital channels are mainly used for the
data acquisition system although five analog channels
are used by RMCS for sensing water-levels and salinity.
Operator control of the model is by means of push-
buttons and a control terminal in the control room
within the Rijnmond building. A large control desk
houses RMCS control push-buttons and indicator
lights as well as lights and meters driven directly by the
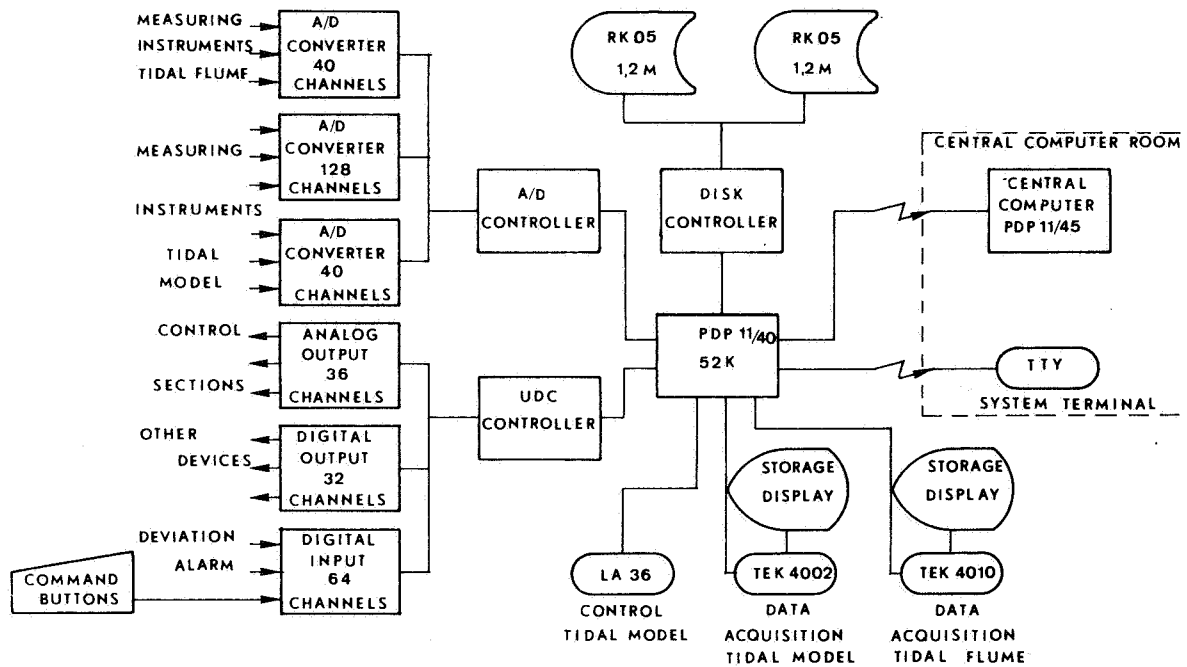model control equipment.

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Fig. 4. Computer system in "Rijnmond" building.

A tide is generated in the model basically by four different control mechanisms :
a. direct flow control along the sea boundaries;
b. direct flow control at the up-river control sections;
c. supervisory control of the water-level at a central location in the model;
d. density difference control between fresh and salt water.
The set-up is shown schematically in fig. 5.

There are two flow-controlled sea-boundaries, the North and the South-side, the West-side is closed. The North boundary consists of five and the South boundary of seven sections. Each section is four meters wide and is divided into two flow controls, one that takes care of the flow into the model and the other one for the outgoing flow. All sections used for flow into the model are supplied with water via a large constant pressure pipeline and a large pump arrangement. The
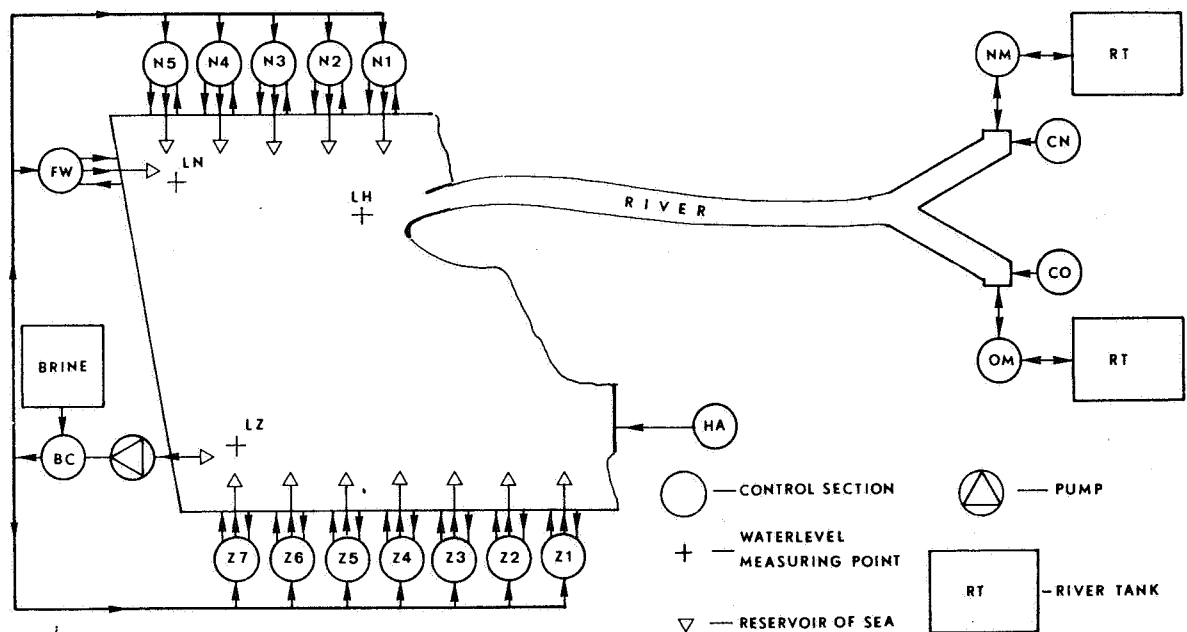

Fig. 5. Tidal model "Rijnmond".

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density control is manipulated in a way that the incoming flow always has the same relative density in comparison with the fresh water that comes from the river ends. Injection of brine takes place on the suction side of the large pumps.

The outgoing flow controls have their own pumps which return the water to a large sump beneath the model which is also connected to the large pump mentioned above. The flow control sections vary in size; the sections nearest to the coast-line have a capacity of about 80 liters per second, while further away from the coast, sizes of about 260 liters per second exist. Fig. 6 shows the northern flow control boundary with its 5 control sections.

The sections are controlled by means of RMCS generated *setpoints* (digital values are converted to analog signals and fed into analog electronic controllers). The flows are measured by electromagnetic flow meters and finally controlled by means of a large number of control valves.

The flow control of the river ends, Nieuwe Maas and Oude Maas, is divided into two different functions. One control is used for simulating the tidal movement because of finite dimensions of the model in relation to nature.

This is done by setpoint control of a storage tank in which the tank level is varied yielding a variation in flow out and into the model. The other one, the upper river discharge which is fresh water, is mostly a constant value during one experiment and is set by hand. For investigations in general water management, the water level in front of the mouth of the river (marked LH on fig. 5) has to be very close to a desired tide curve. From a control point of view, the water-level is a dependent variable because all other controls are independently setpoint controlled. For this reason a supervisory control in the RMCS system is made that takes care of adjustment procedures and after that keeps the water-level deviations within fixed limits. In addition to the controls above, there are a number of digital input signals and single-shot and latching digital output signals handling such things as alarms, push-buttons, model clock time, camera shutters, and recorder pulses all under the control of RMCS software.

4. MODEL OPERATION AND EXPERIMENTATION

The RMCS system separates tidal simulation into four distinct phases : preparation, start-up, adjustment and measurement. Movement between these phases is under operator control. Each phase has different requirements and objectives.

The preparation phase, activated by terminal command, prepares for tidal simulation by first performing initial dialogue with the operator. In this dialogue the software system requests the user to input such information as the number of the tide to be simulated and the water-level measuring locations to be used. After the dialogue, the system prepares for a simulation by reading in necessary data from disk and making some internal computations.
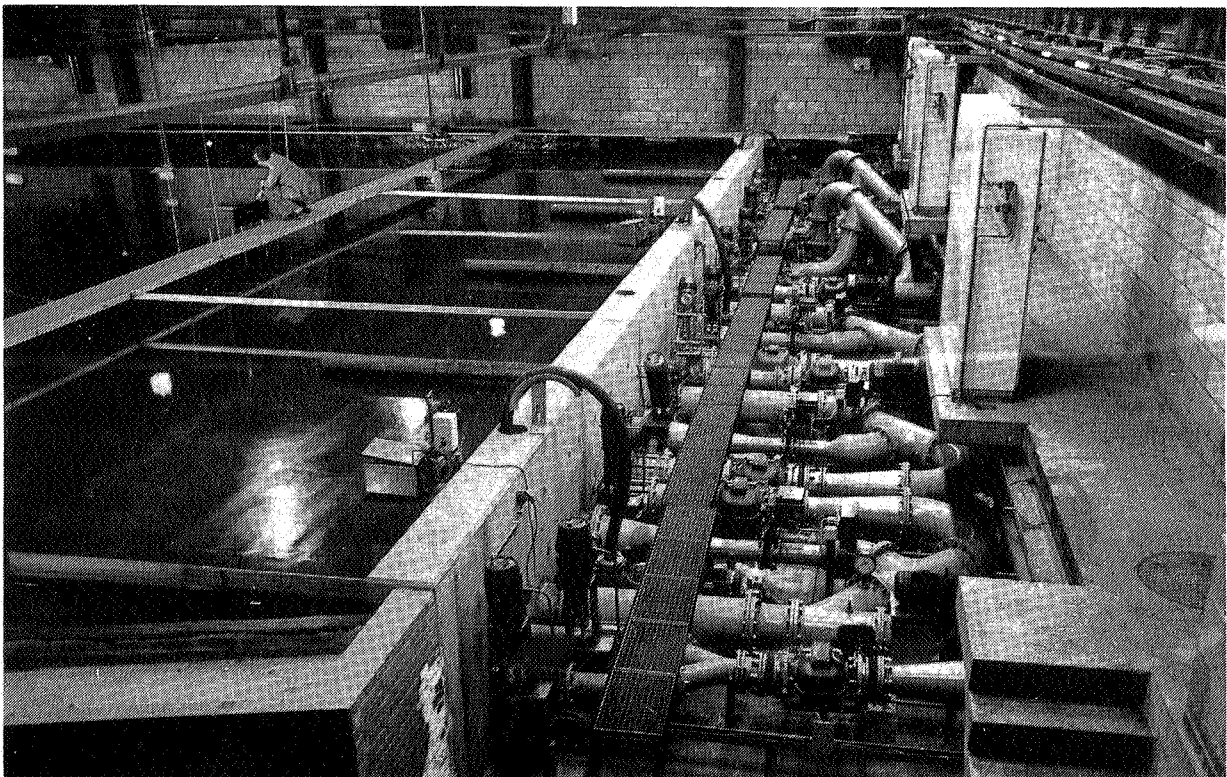

Fig. 6. The North flow control boundary

During this phase the operator manually uses several sea boundary sections to fill the model with water to the correct start water-level indicated by the control system. He is aided in this preparation by alarm messages printed on the model terminal generated whenever the control system senses a water-level change from good to bad or bad to good. The operator must also manually turn on three large sea pumps, the rest of the sea-boundary pumps and river pumps. The starting liter per second setpoint of the river controllers is automatically set by the RMCS system.

The start-up phase, activated via a console desk button after the preparation phase, must be done each day the model is started. Its function is to eliminate initial effects in the model such as incorrect salinity at the mouths of the rivers.

During this and the phases to follow, the model is under complete control of the RMCS software. The start-up phase usually proceeds for six or sometimes more periodic tidal cycles of a length of 25 model hours per cycle (18 minutes 45 seconds real-time). For new tides the operator activates an adjustment phase after start-up in order to dynamically adjust the tide's controlling setpoints. This is necessary because only rough initial values for the Fourier functions of the sea and river boundaries are provided by the Laboratory. These are derived from data gathered by the Rijkswaterstaat, the Dutch Ministry of Public Works, and a mathematical model is used to prepare the Fourier functions suitable for input to the control system. The adjustment phase is performed in order to fine adjust the control functions delivered by the mathematical model. The operator can perform both manual or automatic adjustment of the control functions during this phase by comparing the water-level actually realized at the measuring locations to the water-level desired.

The adjustment can be made either to the control Fourier functions themselves or to the corresponding setpoints that are computed from the functions. The adjustment phase need only be performed on new tides and usually takes ten to twenty tidal cycles. We shall cover the tidal adjustment methods in a little more detail in Section 5.

The measurement phase is performed after the model has been started-up and is usually activated only for adjusted tides. During this phase the task of the control system is to continuously perform operational and supervisory functions including :

. Sending control setpoints;
. Generating signals for the data acquisition system, model clocks, cameras, side force meters and recorders;
. Making small automatic adjustments to a small capacity sea control section to account for minor deviations of realized to desired water-levels. This is called Mean Water-Level Control;
. Monitoring and storing realized water-levels. This is called Water-Level Curve Control(FW in fig. 5)
. Monitoring the density of the water in the rivers. This is called Salt Tongue Control;

. Alarm sensing and logging of status transitions.

It is in the measurement phase that the experiments are actually performed. A specific tide is generated continuously until the experiment using that tide is completed. Experiments usually last several days and are conducted during normal working hours. At the end of each day tidal simulation is stopped and the model is shut down. The following day the model is started up and after several tidal cycles the experiment can continue in the measurement phase.

5. TIDAL ADJUSTMENT

There are two types of adjustments which can be performed on any tide : manual and automatic. The manual adjustment provides complete freedom and flexibility to the operator in modifying and optimizing the control functions. A set of commands allows him to change single or groups of Fourier components or setpoints in a number of different ways.

The automatic adjustment processes are predefined methods of adjustment which are operator-activated by a single command during the adjustment phase of model simulation. There are four automatic adjustment methods : A0, H1, H2, H3. The so-called A0 adjustment precedes the H1 and H2 adjustment methods and is used to adjust the A0 terms of the Fourier functions which account for the mean water-level (the higher order terms are periodic, and therefore result in zero flow integrated per cycle). The H1 method computes corrections to the higher order Fourier components of the control functions, while the H2 method computes corrections directly to the setpoints.

All these methods use the difference in the water-level desired and realized at the Hook of Holland measuring location in the model; however, the A0 and H1 methods use the differences in the Fourier components of the water-level, and the H2 method uses the difference in the values of the time series of the water-level. These methods need the results of a complete tidal cycle to be able to perform the adjustments.

The H3 adjustment is somewhat different in method from its counterparts. It does not use the realized water-level at all to compute corrections. This method computes the water-level that can be expected with the applied setpoints and compares that with the desired water-level and then corrects the controlling setpoints. After the adjustment process has been satisfactorily completed any difference between the desired and realized water-level is reduced by a continuous mean water-level control.

6. CONTROL METHODS

The setpoints to be sent to the control sections to generate a tidal period of 25 model hours consists of 150 values per control section and are stored on disk. Since each tidal period is 18-3/4 real minutes, a new setpoint could be sent to each of the 27 control chan-

nels every 7-1/2 real-time seconds. However, for improving accuracy, linear interpolation is dynamically performed between the setpoints such that updated setpoints are sent every 0.1 second to the controllers.

To check that the correct water-level is realized, the actual water-level is measured 150 times per cycle and compared with the required water-level. For adjusted tides the comparison is used to calculate settings for a sea-control section with the small capacity of 12.5 liters per second. This small correction to the water-level dynamically adjusts for the inaccuracy of the model controls and prevents the mean water-level from slowly deviating too much from the required level. The operator can specify if he desires the correction to be made every 7-1/2 seconds throughout a tidal cycle or at the end of a complete cycle.

7. OPERATOR INTERACTION

The task of the operator is supervisory in nature. He must ensure that the tide is generated as required for the experiment. His actions are limited and include : checking that the model is functioning properly, sequence control of the phases of model operation, setting up equipment such as cameras and water-level recorders, and acting on exceptional situations. The information exchange between the operator and the control system is via a terminal and four console but-

tons. Feedback information is provided to him by means of several control lamps and signals which keep him informed about the current status of the simulation. Important information, such as alarms, phase changes, and water-level deviations, is continually logged on the terminal so that a history of the simulation can always be reconstructed. See fig. 7 for an overview of the control room.

There are a set of possible terminal commands available to the user. Terminal commands and their parameters are standardized in format for ease of usage. The most critical part of the operator's work is during the adjustment of a new tide. Originally in this adjustment process a model engineer (who defines the type of tide and experiment and interprets the results) was involved. However, after one year's experience the engineer's presence is not normally required.

8. RMCS DATA FILES

A very important and extensive part of the RMCS system is a collection of data files and the software facilities to support them. All tide related data is stored on disk so that each tide is uniquely identifiable and reproducible. Each tide consists of a number of disk files containing all relevant information necessary for tidal simulation (see fig. 8). For controlling functions, desired water-level and realized water-level, it is necessary to have files for both Fourier components and
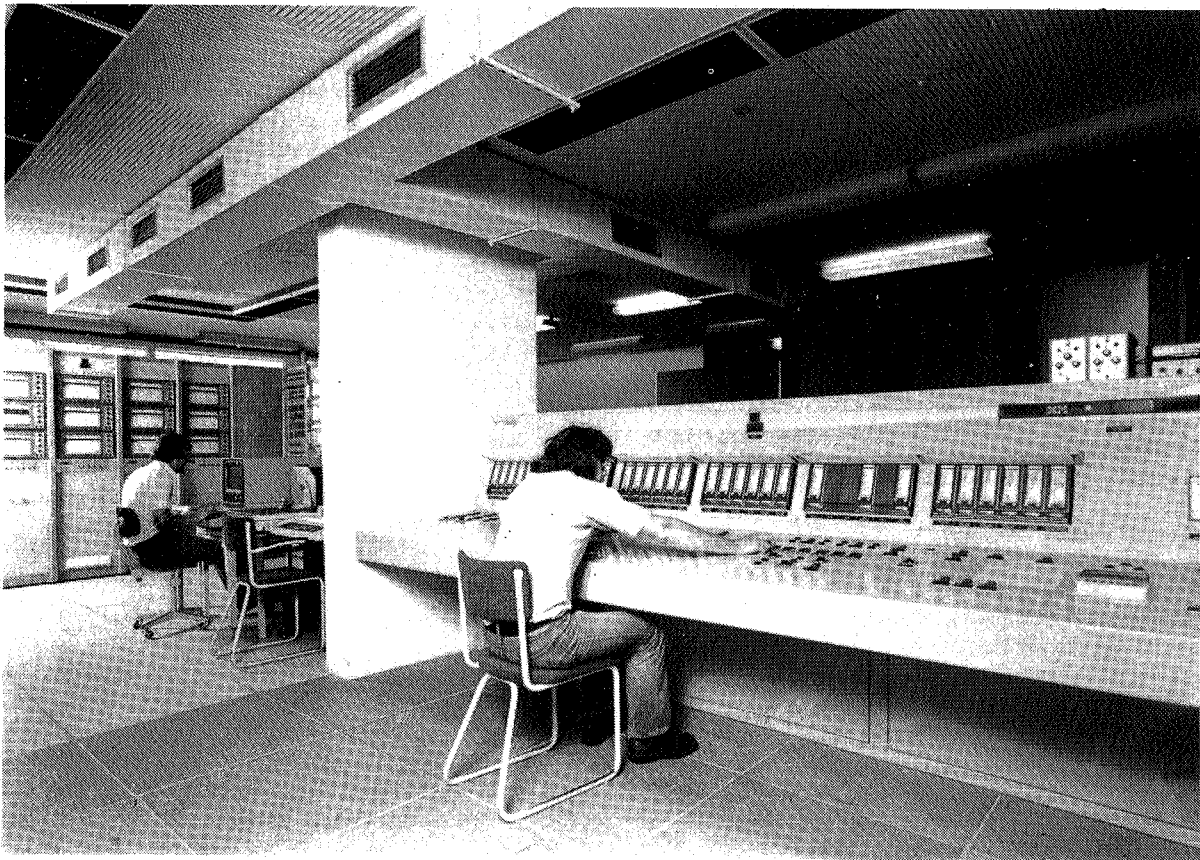

Fig. 7. Overview of control room.

associated setpoint values. The data of the water-level desired and realized can be compared for determining accuracy and performing adjustments. Apart from these files directly related to a tide, there are files which contain more general information such as scale factors and photo taking times.

A disk file utility program is used to access the data files via a set of operator commands. If this utility is used stand-alone, all files are accessible for inquiries and new tide or general files can be created or updated. If run with the operational phases (i.e., preparation, start-up, adjustment and measurement) tidal data for the current tide being simulated can only be *modified* by the utility program if the model is in the adjustment phase.

Tide Files (nn = tide number)

GnnFRS	Fourier Components of the Control Sections
GnnFOM	Fourier Components of the Oude Maas
GnnFNM	Fourier Components of the Nieuwe Maas
GnnFGH	Fourier Components of the Desired Water-Level Hook of Holland
GnnFGN	Fourier Components of the Desired North Water-Level
GnnFGZ	Fourier Components of the Desired South Water-Level
GnnFRH	Fourier Components of the Realized Water-Level Hook of Holland
GnnFRN	Fourier Components of the Realized North-Water-Level
GnnFRZ	Fourier Components of the Realized South Water-Level
GnnSRS	Setpoints of the Control Sections
GnnSOM	Setpoints of the Oude Maas
GnnSNM	Setpoints of the Nieuwe Maas
GnnSHA	Setpoints of the Haringvliet
GnnWGT	Desired Salt Tongue Values
GnnWRT	Realized Salt Tongue Values
GnnWGH	Desired Water-Level Hook of Holland
GnnWGN	Desired North Water-Level
GnnWGZ	Desired South Water-Level
GnnWRH	Realized Water-Level Hook of Holland
GnnWRN	Realized North Water-Level
GnnWRS	Realized South Water-Level

General Files

GnnBIB	Tide Directory
SFDOOD	Scale Factors Neap Tide
SFNORM	Scale Factors Normal Tide
SFSNOR	Scale Factors Spring Normal Tide
SFSPLN	Scale Factors Spring Plus Tide
SFDIVS	Other Scale Factors

Experiment Files

| FOTOmm | Photo Times file mm |
| DKRMmm | Side Force Meters file mm |

Fig. 8. RMCS disk files.

Modification of tidal data is never done in core but always via disk. Thus up-to-date values are always on disk and the process of getting information when using the utility as a stand-alone program is the same as when using the program concurrent with simulation. Tides which have been satisfactorily adjusted can be locked by the user, thereby preventing any further inadvertant modification.

9. SOFTWARE

The RMCS software is developed under the Digital Equipment RSX-11D operating system. This system provides many powerful features for real-time system development and support including real-time calls in FORTRAN and several types of task activation (e.g., based on time or based on event flags). The operating system has facilities for inter-task communication, supports multi-terminal and multi-task execution and provides extensive file support.

The RMCS software is composed of 17 independent tasks. A task under RSX consists of a main program and any number of sub-routines. Some inter-task communication of RMCS is accomplished by system common area allowing both reading and writing by the tasks. The root of the entire control system is the task which controls the sending of control section setpoints. That task remains active all the time the tide is being simulated, but is usually in the wait state. The operating system triggers an event flag every tenth of a second allowing the task to first send its already computed control setpoints, then computes new setpoints for the next trigger. This main task also controls the execution of the task which manages the change of each new tidal cycle, and the task which reads in data from disk. The RSX operating system has proven very satisfactory in support of the rather complicated task activation necessary for this real-time project.

In total the RMCS system is composed of over 100 FORTRAN programs (totalling 7500 executable statements) and three programs written in PDP-11 Assembler. The tasks run in two separate partitions of the computer. One 12.5K word memory partition is dedicated to the RMCS programs which demand quick response. The other 13K word partition supports the lower priority RMCS tasks as well as data acquisition tasks of other systems. (The size of this partition is actually dictated by the non-RMCS users of the partition).

10. PLANNING, IMPLEMENTATION AND TESTING

The initial study, preliminary design and detailed design for the software system was done in 1974. During 1975 the programming and testing of the software was performed on a PDP 11/45 with simulated input and output rather than on the final controlling PDP 11/40. Concurrent to this system development, the new control system was installed in the model including concrete works, mechanical constructions and the rebuild-

ing of the river parts of the model. Therefore, the model was out of operation for one year. In mid-1976 the RMCS system was installed on the final hardware and a period of about one month was used for system testing. In August 1976 the system went into full operation after approximately a month of operator training.

The total effort for software development was approximately two man-years and was according to the original estimates.

11. CONCLUSIONS

In summary, the RMCS system fully meets the original goals. The adjustment process makes fast and flexible adjustments possible. Usually within one or two days a complete new tide can be adjusted.
The flexibility in operation is more than adequate as already demonstrated by experience. The library of tides is very useful and changing to a different tide no longer presents problems. (In October 1977 about 40 different tides were adjusted and in use for all kinds of experiments. Before the RMCS system only a couple of different tides per year had been simulated due to the problems involved in tide adjusting and reproducibility.)
The reproducibility of tides is good, the water-level is accurate within 0.1 mm for comparable times in different tidal cycles. Usually the desired tide can be accurately approximated by the adjustment process so that the difference between the desired and realized water level is less than 0.2 mm at any time in the tidal period.

The *System Development Methodology* or SDM was adhered to throughout the entire software development. This method dictates a unique phasing of the development process : definition study, preliminary design, detailed design, program development, testing and implementation. Also extensive reporting is mandatory. It is thought that adherence to this method has significantly contributed to the success of the project.
The RMCS has been developed by the software house, PANDATA BV, in close collaboration with the Delft Hydraulics Laboratory. This combination of different disciplines and experiences proved to be a highly successful approach.

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