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ORIGINAL RESEARCH ARTICLE

A comparison between the suspended sediment concentrations derived from DELFT3D model and collected using transmissometer — a case study in tidally dominated area of Dithmarschen Bight

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Summary The objective of this investigation is to verify the deficiencies that incorporate both modelled and measured suspended sediment concentrations (SSC) data in a tidal dominated area. For this purpose a tidal channel, in the North Sea, was considered as the case study.

The profiles of SSC from a model were compared with those from the field, in which some dissimilarity was observed. Intensive investigations were carried out to detect that the most discrepancies occur in shallow parts of the area and also during the low velocities. The origin of the shortcomings in regard with the modelling and measuring technique are discussed.

1. Introduction

The lack of sufficient and adequate field data on one hand and the lack of universally accepted equations and parameters on the other hand make the prediction of the sediment transport a challenging topic. Optical devices, such as transmissometer, which is an appropriate instrument in this regard, associate with some shortcomings. Numerical models also face difficulties to simulate suspended sediment concentration.

This investigation focuses on the accuracy of the suspended sediment concentrations (SSC) collected in the field

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using transmissometer, as well as simulated by a model developed using Delft3D package. For this study Piep tidal channel system located in the southeastern part of the North Sea was selected as the case study.

Transmissometer is an optical device had been used to collect SSC along the depth. These data had been collected along at several monitoring points of two cross-sections for duration of one full tidal cycle. To simulate SSC Delft3D software was employed. This software had been used before to simulate the hydrodynamics of the channel (Escobar, 2007). The model was executed for the same period as the measuring cruises. Also the same monitoring points, as those in the field, were introduced to the model.

The SSC results derived from the model were compared with those collected at the field using several methodologies. The deviation between the model results and the filed data in each method is presented and presumable reasons are discussed.

2. Area under investigation

The area under this investigation is central Dithmarschen Bight (Fig. 1). It is located in the southeastern part of the North Sea and is confined from the north by the Eider estuary and from the south by the River Elbe. The area is tidally dominated and known as a well-mixed body of water, with the tidal ranges up to 4 m. The most dominant morphological features of the area are tidal flats, tidal channels and sand banks over the outer region. Under moderate conditions the maximum mean water depth in the tidal channels is about 18 m, and approximately 50% of the domain falls dry at low tide.

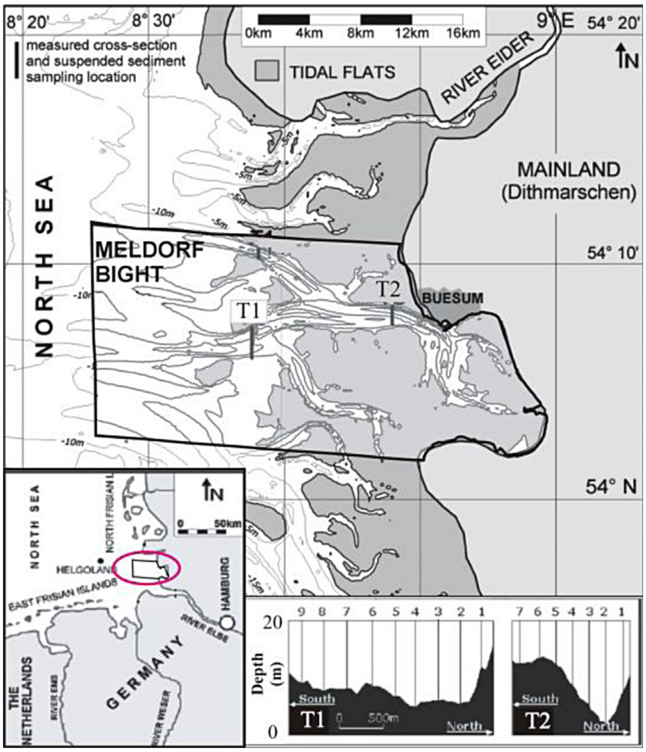

Figure 1 Area under investigation.

The Norderpiep channel in the northwest and the Süderpiep channel in the southwest are the two main branches that drive out from the North Sea into the Dithmarschen Bight. Crossing through tidal flats eastward, the two channels merge to form the Piep channel (Fig. 1). The three channels together form the Piep tidal channel system, which has the shape of a lying Y. The width of the channels and their rivulets varies spatially and temporally from a few meters to about 4 km. The water depths of the main channels vary from 5 m to 25 m. This channel system was specifically selected for the simulation, because of the availability of measured data.

3. Material and methods

3.1. Field data

The source of the required field data for this study was those collected under "Prediction of Medium Term Coastal Morphodynamics", known as the PROMORPH project. It was executed during the period from May 1999 to June 2002.

The data used in this study cover two cross-sections in the Piep tidal channel system: T1 in the Süderpiep channel, and T2 in the Piep channel (Fig. 1). The width of the channel at cross-section T1 and T2 is about 2040 m and 1200 m respectively. The water depth varies from 7.3 to 15.6 m at cross-section T1, and from 6.2 to 17.9 m at cross-section T2.

Acoustic Doppler Current Profiler (ADCP) had been used to measure current velocities. The instrument was mounted at the bow of the vessel pointing downward. Measurements covered the water column from about 1.6 m below the free surface, due to transducer draught and blanking distance, down to the seabed. The vessel moved forward and backward along each transect during a full tidal cycle collecting ADCP data along the route. Vertical profiles of the current velocity thus were collected for the whole period of the tidal cycle. Fig. 2 shows the procedure schematically. According to Jiménez Gonzalez et al. (2005) the accuracy of the ADCPs are approximately constant in the tidal channels of the central Dithmarschen Bight. They evaluated the averaged accuracy of the device with value of about 0.15 m/s.

An optical beam transmissometer device has been employed during the cruises of the PROMORPH project to collect SSC. For collecting data at different levels along the depth, the transmissometer together with one CTD (Conductivity, Temperature, and Depth) device was mounted on a frame. In each cruise the frame was lowered at several monitoring points at each cross-section from the surface to near the bottom to collect data (Fig. 2). The interval between every two nearby stations was about 180 m. The CTD device in the frame was responsible to provide the height at which the beam scatter data were collected. Optical transmission data collected in this way were converted to SSC, using the equation proposed by Poerbandono and Mayerle (2005).

$$c = (7A + 33)10^{-3} \tag{1}$$

in which c is concentration of sediment, and $A = -L^{-1}\ln(I)$ is the attenuation coefficient, with L and I being the transmissometer path length in cm, and the optical transmission as a decimal fraction respectively.

3.2. Modelling

To obtain reliable results from models, a comprehensive knowledge of the processes involved is necessary. Delft3D model, which represented high accuracy in the field of hydrodynamics (Palacio et al., 2005), was used for this simulation. The boundaries of the model have been chosen far from the area of interest, which has ensured that the boundary conditions will not affect the hydrodynamics and sediment dynamics of the monitoring points. The area which has been chosen for the modeling is shown in Fig. 1 by a black curve.

The model consists of one closed land boundary at the east and three open boundaries in the north, west, and south. For the open boundary input data in terms of water levels were considered. It was the decision due to the availability of long-time data collection at the field. The grain size map of the area was developed by Escobar (2007). He carried out intensive experiments and determined a functional relationship between flow characteristic and grain size distribution. Regarding the sediment properties, altogether five sediment fractions were used, of which four describe the non-cohesive sediments and one represents the mud fraction. The grain size distributions were prepared by Poerbandono and Mayerle (2005) on the basis of the sampling and sieving. They found that the d_{50} varied between 80 μm and 230 μm, corresponding to very fine ($63\ \mu\text{m} < d_{50} < 125\ \mu\text{m}$) to fine ($125\ \mu\text{m} < d_{50} < 250\ \mu\text{m}$) sand, respectively. The resulting sieve curves are shown in Fig. 3. They also mentioned that the median sediment sizes of most of the samples were equal to or less than 100 μm and that the majority of the samples were well sorted. The grain size characteristics of the sand fractions, on the basis of their measurements, were selected to be 100 μm, 115 μm, 135 μm and 180 μm. These fractions account for 75% of the sediment mixture of the area. The mud content and properties of the non-cohesive sediment fraction were those derived from sediment samples taken at several locations as reported by Poerbandono and Mayerle (2005).

According to Rahbani (2011) the effect of waves under moderate winds having velocities less than 11 m/s is ignorable at the analysed site. In the simulations therefore, considering moderate conditions during all the campaigns, the effect of wind-induced waves was withdrawn.

The hydrodynamics of the model was calibrated and validated by Palacio et al. (2005) using collected ADCP data. They reported the mean absolute error of less than 0.2 m/s between computed and observed velocities at various cross-sections in the tidal channels. They also claimed that this value represents less than 20% of the tidally averaged value, which can be considered as an acceptable result for the hydrodynamics model.

The sediment dynamics of the model was calibrated by Rahbani (2011). Tuning critical bed shear stresses for erosion

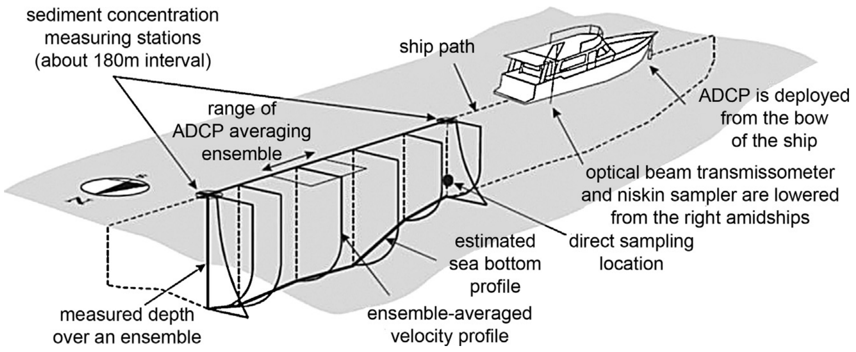

Figure 2 Measuring technique along a cross-section.

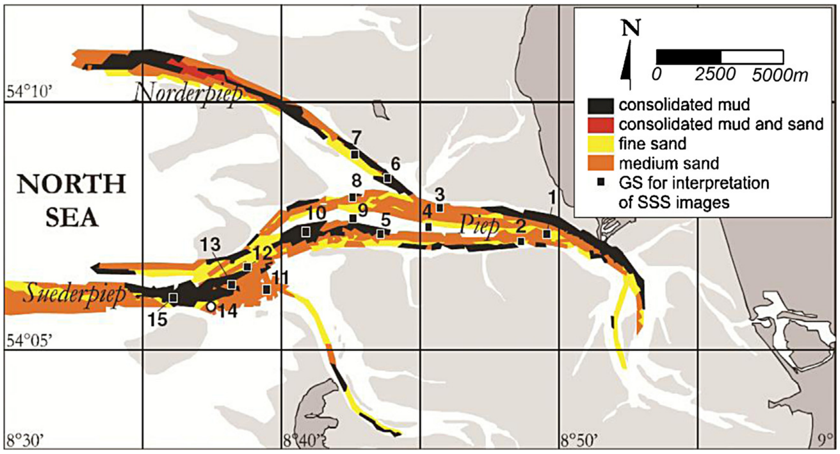

Figure 3 Seabed surface sediment distribution in the main tidal channels (according to Poerbandono and Mayerle, 2005).

and sedimentation has been used for the calibration. According to her results the RMAE errors in each cross-section show significant improvement. However she reported rather poor correlation between the model results and field data.

4. Results and analysis

As a first analogy the variation of the current velocity and the SSC along the depth obtained from the model are compared with those collected in the field for all monitoring points. The model results had been extracted in such a way that their times and locations were matched with the times and the locations of the field data. The time difference between the field data and the model results for comparison never exceeded 5 min, and the spatial difference of the points in the field data and the model did not exceed 50 m. This was found reasonable in view of the grid length being 90 m. Typical profiles of the velocity and SSC for all monitoring points in cross-sections T1 and T2 are presented in Fig. 4 for one ebb condition. The sets of data are those collected from 21 to 23 of March 2000, covering a sequence of spring tides with an average tidal range of about 4 m.

It can be seen that the current velocity profiles derived from the model are in good agreement with those from the field which also approves the results obtained by Jiménez Gonzalez et al. (2005). For the SSC profile however, some dissimilarity was observed between the model results and the field data.

In cross-section T1, the SSC profiles derived from the model are generally in good agreement with the field data in monitoring points 1, 2 and 4. Marked disagreement is evident between the model results and field data in profiles 3 and 5—9, especially from the near bed layer to the middle of the depth. In cross-section T2 underprediction by the model is evident in all of the monitoring points except for profiles 1 and 2. Likewise, comparisons between the SSC profiles derived from the model and from the field during a full-tidal cycle revealed certain dissimilarities at shallow parts of the cross-section.

Observing such dissimilarities in shallow parts, it was decided to detect the relevance between the predicted (model results) and observed (field data) SSC with respect to the depth. Therefore, the ratios of the observed to the predicted SSC along the depth were calculated at each cross-section. Figs. 5 and 6 show results for cross-sections T1 and T2 respectively. At each cross-section two monitoring points, one in shallow part and the other in deeper part were considered. In each figure, the plots in the left show the ratios during a whole ebb phase and the ones in the right show the ratios for duration of a flood phase. The monitoring point in a shallow part of the cross-section and its corresponding

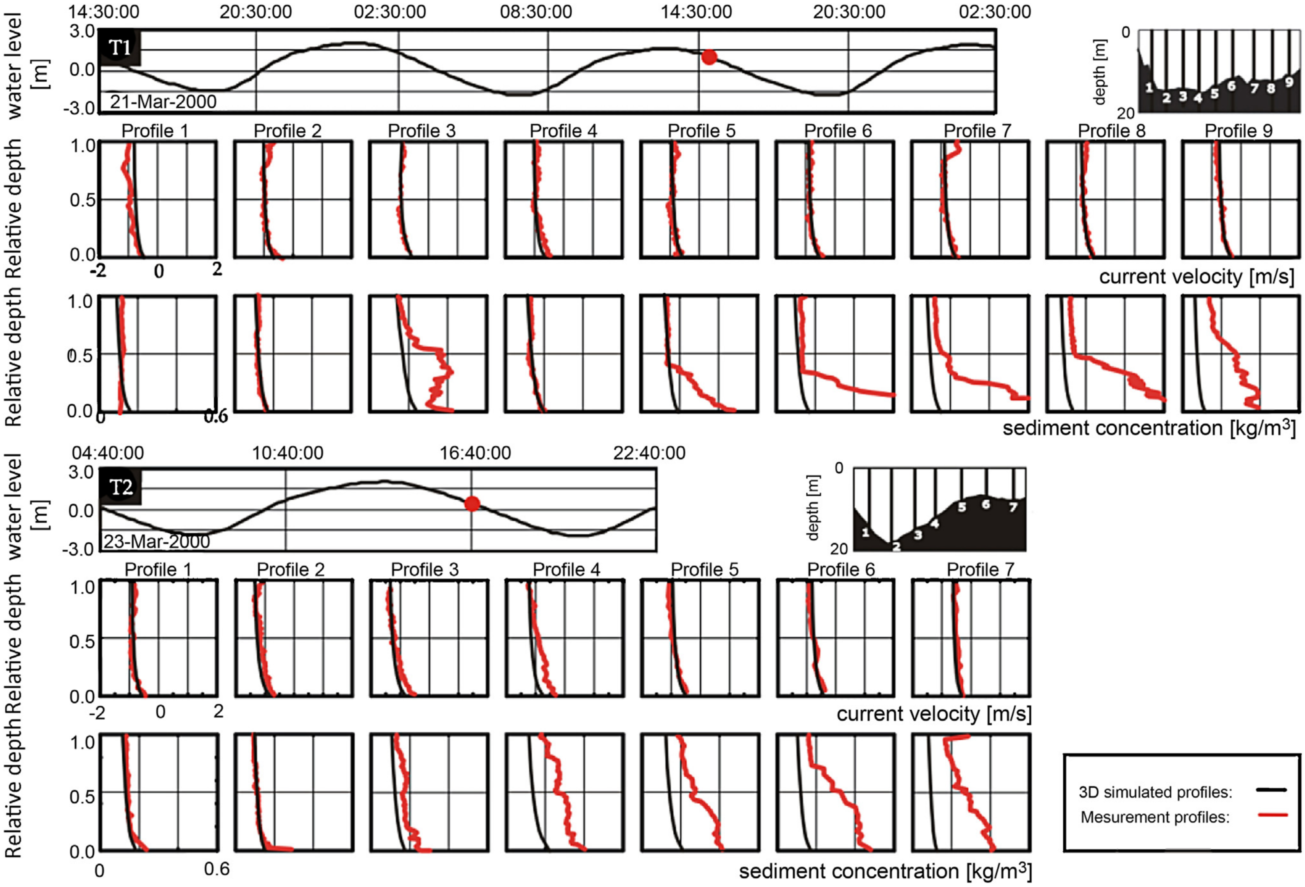

Figure 4 Current velocity and suspended sediment concentration profile derived from the model and in situ measurements during the *ebb condition* for cross-sections T1 and T2.

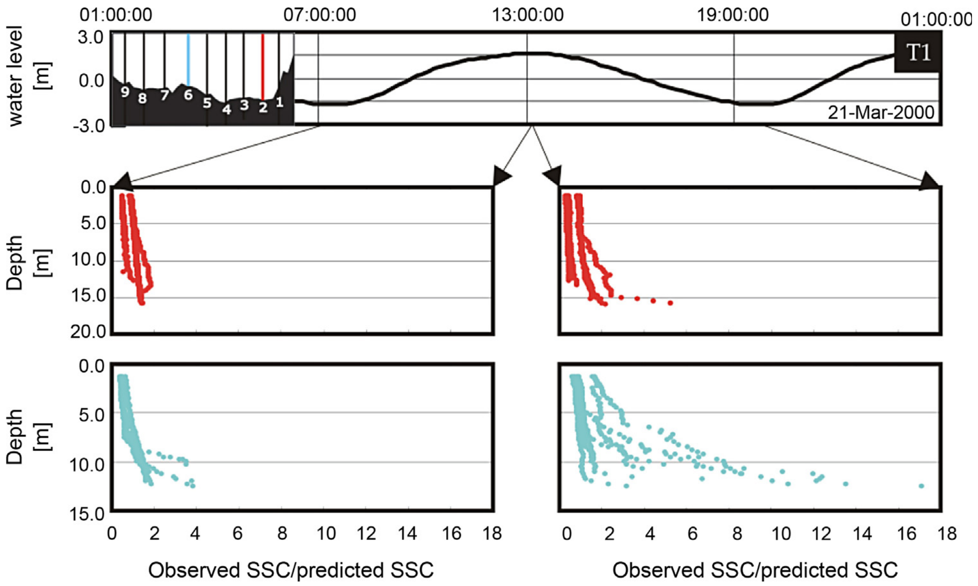

Figure 5 The ratio of observed to predicted SSC along the depth for monitoring points in deep water (red) and in shallow water (blue) at the cross-section T1 during one ebb phase (left plots) and one flood phase (right plots). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

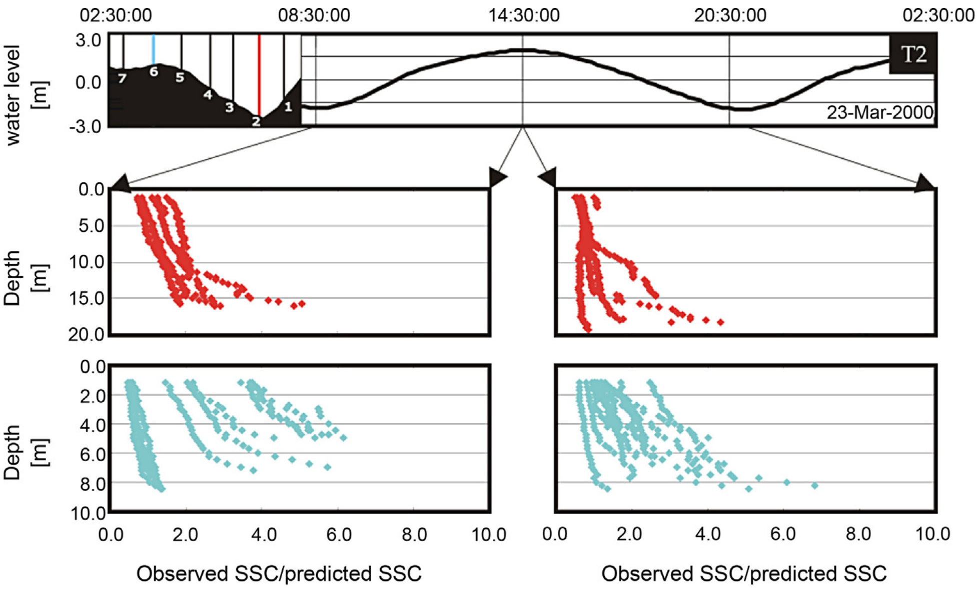

Figure 6 The ratio of observed to predicted SSC along the depth for monitoring points in deep water (red) and in shallow water (blue) at the cross-section T2 during one ebb phase (left plots) and one flood phase (right plots). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

results are shown in blue and those for the deep part are presented in red.

It is obvious on the figures that observed SSCs in shallow parts are appreciably higher than predicted ones. It can also be seen that the ratio of observed to predicted SSCs are much larger during the ebb phase than that during flood phase especially in near bed layers.

It can be seen from the results that the deviation between the model results and field data do not show similar trend along the depth. Taking into account that the model has been calibrated against SSC, observing such deviation can be attributed mostly to the field data. Therefore dissimilarities observed specifically in the shallow regions are expected to be related to the existence of some error in measuring devices. Existence of biological matter and generation of air bubbles in such regions can be counted as the reason for the error in measuring device.

5. Conclusions

Suspended sediment concentrations measured in the field using transmissometer were compared with those derived from Delft3D model. Dissimilarities between the modelled and measured SSC were mainly observed in the shallow regions of cross-sections T1 and T2. This was supposed to be partly due to in situ measurements' shortcomings and partly was attributed to the imperfections of the theoretical modelling approaches incorporated in the Delft3D software.

Wide range of particle size distribution in shallow water areas could be counted as a possible reason for the dissimilarity observed. Gordon and Clark (1980), Bishop (1986), Moody et al. (1987) and Bunt et al. (1999) reported that the variation in particle size distribution is the most influential physical characteristic of the sediments on the response of optical devices. Bunt et al. (1999) suggested that variations in floc size could double the variation in instrument response for similar mass concentrations. Existence of biological matter in shallow water area can also affect the recorded data by transmissometer. As pointed out by Walker (1981), biological matters such as chlorophyll-*a* and phytoplankton even though relatively insignificant by mass, their effect on the response of optical instruments is significant. These organisms are known to be active in the shallow areas where light is sufficient. The sticky nature of these particles causes flocculation between the fine particles. Ebb conditions are favourable for their activities because of the decrease in the water level and increase in the transmitted light. Discrepancy in transmissometer results could also be due to air bubbles originated by water organisms. Bunt et al. (1999) and Campbell et al. (2005) reported the significance of air bubbles to the response of the optical backscatter devices. They reported that air bubbles can double the response of the device.

In addition to the errors that resulted from the measuring device, the discrepancies between the field data and the model results can be caused by improperly defined input data, namely the sediment features or the model tuning parameters.

It should also be mentioned that Delft3D is incapable of simulating the interaction between the individual fractions, especially between sandy fractions and the mud.

The use of a constant settling velocity for the whole area and for the whole tidal cycle can be counted as another model limitation. This is the limit associated with the Delft3D modeling which does not allow the use of variable values of settling velocities over the area. According to Winterwerp (2001) there are large variations in the value of the settling velocity having the higher values around the slack water mainly due to flocculation of sediment. His conclusion is that flocculation is a factor that explains why it is not possible to simulate the observed features in suspended sediment concentrations properly using constant settling velocity. Talke and Swart (2006) also emphasized the necessity of considering variation of the settling velocity during a tidal cycle in order to simulate the behavior of the suspended sediment. In their investigations they showed that biological matters and turbulence processes play an important role in the variation of the settling velocity during a tidal cycle.

Considering constant settling velocity for the tidal channel and the tidal flat can affect the results in a way that the model could not properly simulate the amount of sediment washed out from the land and the tidal flat areas through the channel during the ebb conditions because of the insufficient supply of sediments. This is applicable specifically to the cross-section T2 due to its proximity to tidal flats and the water-land interactions (see Fig. 4). The SSC values obtained from the model during ebb condition show mostly underprediction for this cross-section.

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