HYDRAULIC MODELING - MAPPING OF RIVER BED

Geisler T., **Breitenstein S.**, **Hammer A.**, **Mayr D.** and **Klasinc R.**
Graz University of Technology, Hermann-Grengg Laboratories
Institute of Hydraulic Structures and Water Resources Management
Stremayrgasse 10/II, A-8010 Graz, Austria
Tel.: +43 316 873-8364, Fax: +43 316 873-8357
klasinc@kwb.tu-graz.ac.at

Abstract: Measurement of river bed topography plays a key role for validating sedimentary processes in experimental hydraulics. In addition to contributing to a general understanding of these complex processes, river bed mapping can substantially aid in the design of particular projects. This paper gives a brief description of methods that are currently available for the purpose of river bed mapping in hydraulic modeling: wool threads, depth pointer gauges, digital photogrammetry, and projection Moiré. Lastly, instrumentation used at Hermann-Grengg Laboratories is presented together with an example for its employment on a bridge scour test.

Keywords: river bed mapping, scour measurement, hydraulic modeling

1. INTRODUCTION

Research into experimental hydraulics places considerable emphasis upon the measurement of river bed topography, since measurement of the structure of river surfaces is crucial for understanding both bed roughness and sediment transport. Sediment transport is also an element of great importance in the design, construction and operation of hydro power projects. The main problems in this context are reservoir sedimentation, the potential risk to the vulnerable turbines, and river bed erosion downstream of the dams. Model tests with erodible beds and with a realistic representation of sediment transport thus are an effective means for the study of sediment processes in hydraulic engineering.

For mapping river bed surface within a hydraulic model test, a number of techniques are currently available: wool threads, depth pointers, digital photogrammetry, and projection Moiré. Optical techniques such as photogrammetry and projection Moiré allow to measure the whole river bed surface instantaneously and thus experimental work to continue without delays. The type of sediment is of no importance as long as the contrast provided is sufficient.

2. WOOL THREADS

Contour mapping with wool threads is an old technique. After the test run, the water is slowly emptied. Once the water level reaches say 10 mm below the original surface, a wool thread is laid along the contour of the water table. Then, the water level is lowered another 10 mm etc. Finally, a photograph of the contour lines is taken (Figure 1). Quantitative measurements, i.e. of displaced volume, are possible only if the photographs are evaluated using a CAD method. Since placing the threads is a lengthy job, the method is very time-consuming, especially where a series of test runs is to be carried out.

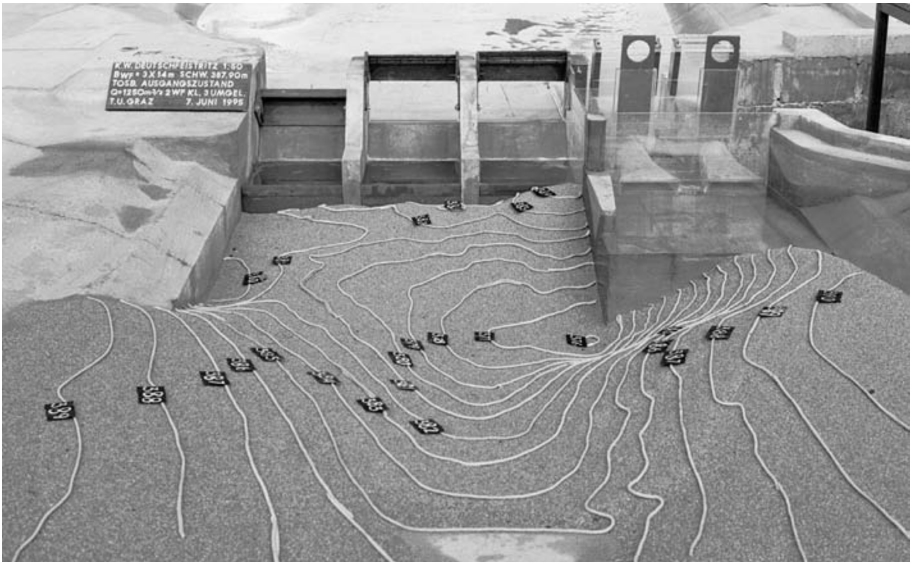


Figure 1: River bed mapping with wool threads.

3. DEPTH POINTER GAUGES

Scanning the river bed by means of depth pointer gauges is based upon a series of individual point measurements that are repeated sequentially over an area. The method employs a tool known as a "point gauge", which consists of a vertical probe clamped on a horizontal bar. The probe is lowered to the bed surface and a simple height change is measured, assuming a horizontal datum. The probe is then moved along the horizontal bar to the next desired location and the measurement is repeated. The nearness of the bed is indicated by a sensor that may work according to different principles. The technique can be operated manually (particularly for very light sediment such as lignite) or automatically. The method is simple but time-consuming and thus its application is usually limited to a set of cross sections that are sampled at wide intervals. Its advantage is the option to measure both above and below the water without producing a discontinuity. River bed movement can thus be observed even during the flowing process.

A commercially available, touch sensitive system is shown in Figure 2 (Hydraulic Research Wallingford, 2002). The vertical probe consists of a 10 mm diameter stainless steel tube which has a rack machined along its length. This rack engages with the gear wheel of the vertical servo motor in the carriage and drives the probe up and down. On the bottom of the probe is a sensor which consists of a lightweight "finger" that can move freely up and down inside a 20 mm diameter cylinder, as displayed in the right side of Figure 2. The position of the finger relative to the cylinder, and thus the probe relative to the bed, is measured optically. A pulsed infrared light source is mounted on top of the probe and light is transmitted to the bottom using optical fibers. Another optical fiber transmits the light reflected back from the top of the finger to a detector which produces a signal that is proportional to the distance between the probe and the bed. The servo electronics control the speed of the probe so that the finger gently touches the bed and stops so that the probe to bed distance is the same for each measurement.

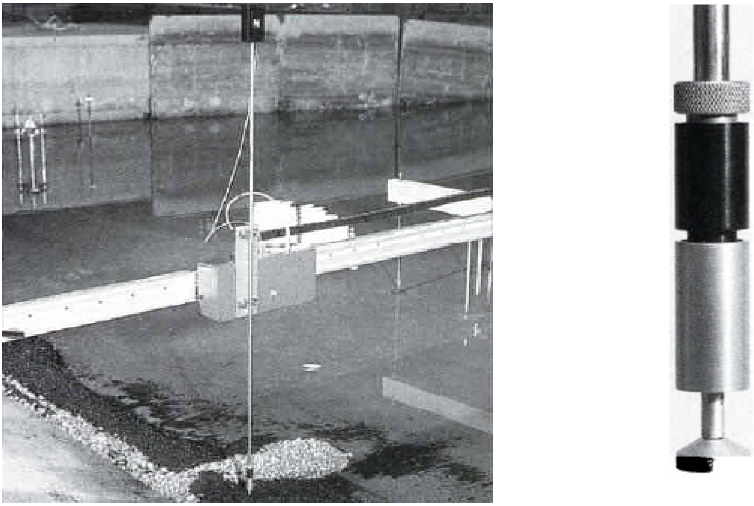


Figure 2: Bed profiling system developed by HR Wallingford; in operation (left), probe sensor (right).

4. DIGITAL PHOTOGRAMMETRY

Until recently, the potential of photogrammetry has been restricted by hardware limitations and high costs for subsequent image processing. With the emergence of digital imagery, the technique has experienced enormous progress. Digital photogrammetry is based upon automated analysis of digital imagery using the basic principle of the perspective projection. Two images of an object are acquired from two separate locations with known coordinates, as displayed on the left side of Figure 3 (Slama, 1980). If at least five points (“photocontrol points”) at known object locations are clearly visible on both images, a spatial resection can be carried out to derive the positions and orientations of the images. With the help of automated stereo matching, conjugate points can be identified and elevation coordinates are extracted.

The desired elevation precision (p) is related to the dimension of individual pixels in the object space or surface of interest (d_0), so that approximately: $p \approx d_0$ (Lane et al., 2001). For vertical photography, the dimensions of a pixel on the object is controlled by the scale of the photography (c/H, where c = focal length and H = camera flying height) and the physical size of the pixel in the image space (d_e). For a digital camera, d_e equates to the physical size of an individual sensor element, as the right side of Figure 3 (Wolf and Dewitt, 2000) illustrates. Thus, the expected precision of derived elevations is given by

$$p \approx d_0 = \frac{d_e}{c/H}$$

To achieve a given precision, and given that c will be defined primarily by the type of lens available, it is possible to alter either d_e or H. In practice, the user has less control over d_e than H because the image space dimension is a fixed parameter for a digital camera. Reducing H can be used to increase precision, but this will also reduce the area of coverage. With a smaller area of coverage, progressively more image pairs will be needed to cover the measurement area. Usually, photocontrol point location dictates the camera flying height: the camera has to be high enough above the flume for the ground coverage to contain all photocontrol points, which have to be installed outside the active river bed to avoid unacceptable disturbance.

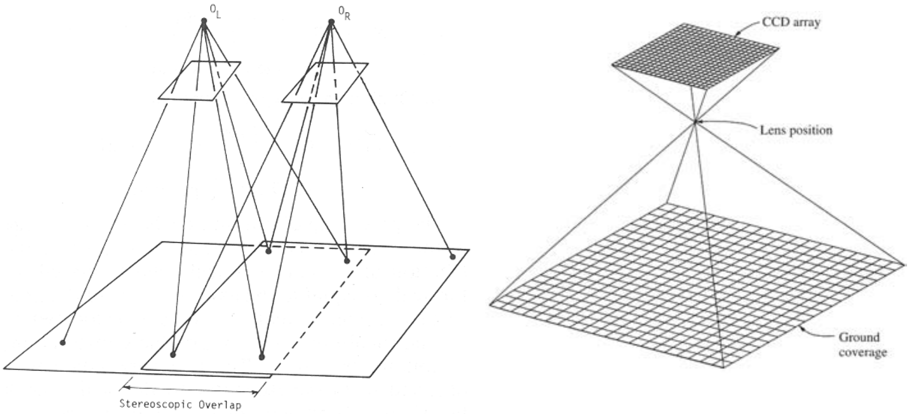


Figure 3: Digital photogrammetry; geometry of stereoscopic coverage (left), and of digital camera (right).

Given image space pixel dimensions (d_e) of 9 µm, as defined by a 3,060 x 2,036 CCD array with known dimensions of 27.6 x 18.6 mm, and a typical value of the focal length of 28.7 mm for a 35 mm camera body, this suggests an optimum vertical precision of 0.6 mm (Lane et al., 2001). The best possible spatial resolution is somewhat coarser than this: if stereo matching using area-based correlation is adopted, the best spatial resolution possible is $5p$, as the matching procedures tend to use a 5 x 5 area-weighted template. In the example, the best possible spatial resolution then is 3.0 mm.

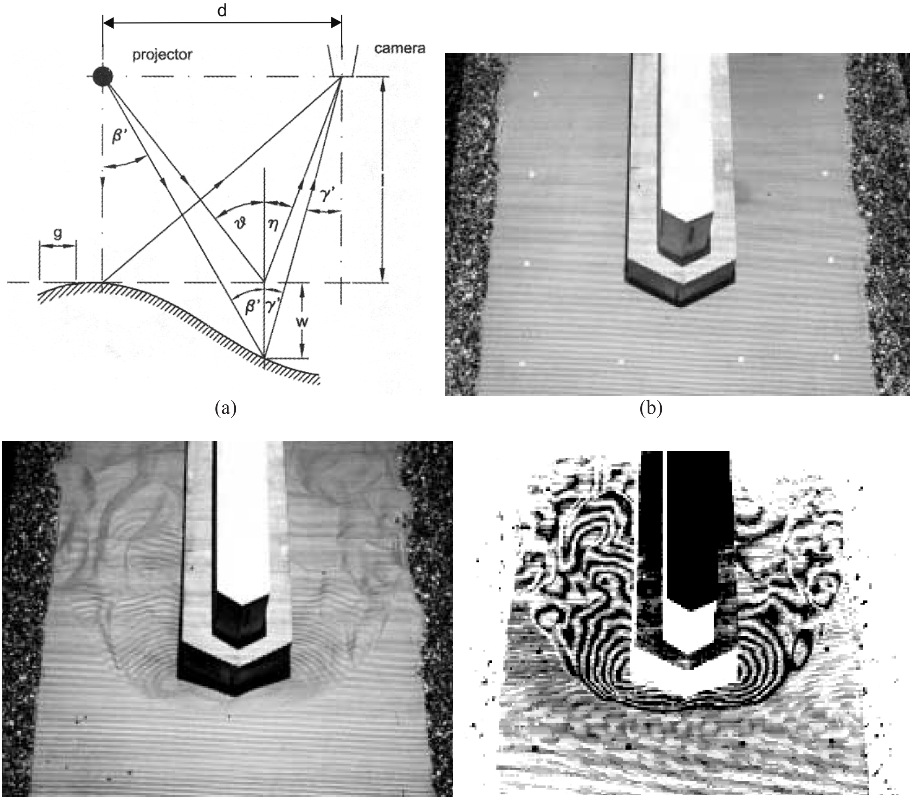
With both analogue and digital photography it is important to obtain adequately exposed images with good contrast. The provision of adequate illumination and selection of appropriate camera exposure settings is therefore critical, since difficult contrasts are provided by the irregular surfaces of wet sand or gravel. One of the major advantages of digital cameras is that no photographic processing is required, and hence it is possible to check image quality immediately and reacquire if necessary (Chandler et al., 2001).

Another critical aspect of photogrammetry is the calibration procedure. The camera must be precisely calibrated to remove errors that are still present in the system. If a specialized camera designed for photogrammetry is used, then a calibration certificate will provide all necessary information. However, photogrammetric or “metric” cameras are very expensive, and it is increasingly common to use “non-metric” cameras. Non-metric cameras can be calibrated in a process called “self-calibration” as a byproduct of the actual measurement, as long as certain requirements are met, for instance, some photographs must be taken with the camera horizontal and some with the camera vertical. A second requirement is that a minimum number of photographs must be taken from a minimum number of different locations. All of these procedures are automatically solved in a process called the “bundle adjustment”, together with the triangulation of the target points and the orientation (position and aiming angles) of each photograph.

Photogrammetry can in principle as well be used to measure submerged river bed topography by adopting a correction for the effects of refraction at the air/water interface. For shallow and clear water situations, research carried out with anti-reflective perspex sheeting to flatten the water surface show promising results (Butler et al., 2002). Scouring experiments, however, involve fast, possibly supercritical flow and disturbed water surfaces, and hence limit the applicability of photogrammetry.

5. PROJECTION MOIRÉ

A technique which is frequently employed in mechanical engineering and in medicine to measure surface distortions or curvatures. A line grid is projected vertically onto an undisturbed reference plane and a photograph is taken with an inclined camera (Figure 4b), whereby the camera angle has to be chosen so that all surfaces can be photographed. The grid is again projected onto the disturbed or deflected surface and another photograph is taken (Figure 4c). Both photographs are then superimposed (Figure 4d). The superposition picture shows a set of dark and bright or Moiré lines, which constitute lines of equal elevation. The technique can also be used with an inclined projector, however, vertical projection is recommendable to avoid a distortion of the grid (Müller et al., 2001).



(a) (b)

(c) (d)

Figure 4: Projection Moiré; geometry with illumination and viewing at finite distances (a), undisturbed picture with reference points (b), scour picture (c), superposition of both pictures showing Moiré fringe pattern (d).

Assuming a collimated illumination beam and viewing the fringes with a telecentric optical system, straight equally spaced fringes are incident on the object, producing equally spaced contour intervals. In practice, however, we have to consider the case of finite illumination and viewing distances, as illustrated in Figure 4a: the illumination angle β and the viewing angle γ change for every point on the surface. The fringe lines obtained are no longer equally spaced, i.e., the height difference between two consecutive fringe lines increases with order number. The development of a set of equidistant lines has to be done during graphic data post-processing. Because of the finite distances, there is also a distortion due to the viewing perspective. A perspective correction must thus be applied using reference points on the undisturbed surface.

The elevation w of a fringe line is a function of the geometry of the experimental setup as displayed in Figure 4a:

$$w = \frac{N \cdot g \cdot l}{d - N \cdot g}$$

where N denotes the order number of the Moiré line, g the distance between two grid lines on the measurement plane, l the distance between camera/projector to the measurement plane, and d the distance between camera and projector (Creath and Wyant, 1992).

The accuracy of projection Moiré depends on the distance between the projected fringe lines, which is ruled by the angle between the illumination and viewing directions. The larger the angle, the smaller the contour interval. Even though the maximum sensitivity can be obtained at 90°, this angle will produce a lot of unacceptable shadows on the object. If the grid is projected via a slide projector, the number of lines printed on the slide also effects accuracy. The grid spacing, though, is limited by the resolution of the digital camera used; 2-3 pixel per line have to be considered essential for a proper image (Müller et al., 2001).

The particular advantages of projection Moiré are low costs and a comparatively easy experimental setup. Its two disadvantages are the requirement for manual digitization (this simply means that the Moiré lines are redrawn and layered within a CAD program), and the ambiguity of the lines with respect to the order number. The pattern itself does not give any information about the height difference with respect to the reference plane, i.e., one cannot judge whether a part showing a fringe is a hill or a valley. The fringe order has to be determined with the help of additional photographs taken during the mapping process.

6. RIVER BED MAPPING AT HERMANN-GRENGG LABORATORIES

In the 1990s, a reliable and cost-effective method for river bed mapping was developed at Hermann-Grengg Laboratories (Klasinc, 1994). In this method, the mechanical depth pointer gauge is replaced by an optical distance sensor, shown in Figure 5. The sensor (Sick DME 2000) measures light travel time according to the principle of phase correlation and transfers the obtained data to a personal computer that controls both the measurement cycle and the probe position. The user is able to control the start point, total distance to be traversed and number of sampling points, and once started, all operation and measurement is fully automatic. The system is capable of measuring very precise distances between the sensor and the river bed and it has the ability to measure directly through shallow water. The narrowly defined laser beam enables high resolution digital elevation models (DEMs) to be generated but the main problem is the speed of data acquisition, with approximately 2 hours required to map an area of 1.0 x 1.0 m with a resolution of 2 mm.

The instrumentation was recently applied in a 1:40 scale model test which was performed to investigate the flood discharge capacity of a new railway bridge across the River Salzach in Salzburg. Tests were made with several flow rates, simulating various high waters at the respective location. After completion of each test run, the river bed topography downstream the bridge piers was mapped and the obtained data were transferred into a CAD program to generate a digital elevation model. To visualize the digital elevation model, contour lines were plotted and superimposed on the digital image of the investigated area. A sample plot is shown in Figure 6. DEMs can then further be utilized e.g. for the volumetric analysis of the erosion process or the validation of numerical simulations.

Figure 5: Measurement setup for river bed mapping at Hermann-Grengg Laboratories.

7. CONCLUSIONS

The objective of this paper is to compare measurement methods currently in use for mapping river bed topography in hydraulic research. Each of the four techniques presented has advantages for specific applications where topographic measurements are required. No technique is best suited for all situations and cost-benefit tradeoffs may be necessary. From a user's point of view, the optimum technique collects 3D coordinates of a given river bed region 1) automatically and in a systematic pattern; 2) at a high rate; and 3) achieves the results in (near) real time.

Photogrammetry and projection Moiré provide information that is of slightly lower quality compared to the other methods. Nevertheless, increased spatial coverage and significant reduction in time suggest that these optical methods will become particularly advantageous in the future. Developments, improvements, and applications will continue.

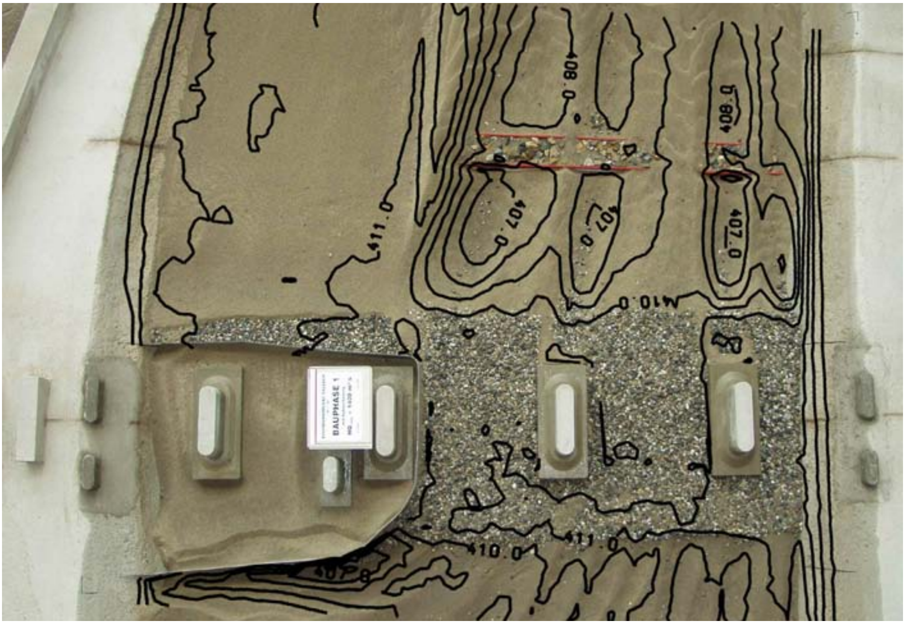


Figure 6: Sample plot of contour lines with a vertical distance of 1.0 m in prototype scale.

REFERENCES

Butler, J. B., Lane, S. N., Chandler, J. H., and Porfiri, E. (2002): Through-water close range digital photogrammetry in flume and field environments. *Photogrammetric Record*, 17(99), pp. 419-439.

Chandler, J. H., Shiono, K., Rameshwaren, P., and Lane, S. N. (2001). Measuring flume surfaces for hydraulic research. *Photogrammetric Record*, 17(97), pp. 39-61.

Creath, K., and Wyant, J. C. (1992): Moiré and Fringe Projection Techniques. In *Optical Shop Testing (Editor Malacara D.)*. Second edition, John Wiley & Sons, pp. 653-685.

Hydraulic Research Wallingford (2002). *Touch sensitive, 2-D bed profiling system for physical models*. Brochure, HR Wallingford Ltd., Oxfordshire (UK).

Klasinc, R. (1994). Measuring instruments for investigating hydraulic models of sedimentation. *Proceedings of the International Conference on Hydraulics in Civil Engineering*, University of Queensland, Brisbane, Australia, pp. 69-72.

Lane, S. N., Chandler, J. H., and Porfiri, K. (2001): Monitoring river channel and flume surfaces with digital photogrammetry. *Journal of Hydraulic Engineering*, 127(10), pp. 871-877.

Müller, G., Mach, R., and Kauppert, K. (2001). Mapping of bridge pier scour with projection Moiré. *Journal of Hydraulic Research*, 39(5), pp. 531-537.

Slama, C. C. (Editor, 1980): *Manual of Photogrammetry*. Fourth edition, American Society of Photogrammetry, Falls Church, Virginia (USA).

Wolf, P. R., and Dewitt, B. A. (2000). *Elements of Photogrammetry*. Third edition, McGraw-Hill.