The Challenges to an Undergraduate Student Team Undertaking A Complex Project

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Abstract

Cal Poly Pomona's Civil Engineering Department offers a capstone course that allows students the opportunity to work in a group on a comprehensive project that will ready them for a career in Civil Engineering. The project discussed in this paper was to evaluate the sediment removal plan in San Gabriel Canyon Reservoirs by the Los Angeles County Department of Public Works (LACDPW), and to recommend alternatives. The sluicing operation requires draining the reservoir and flushing out the sediment at the bottom of the reservoir. During the sluicing operation, the reservoir was not available for flood control. Further, the sediment buildup had created adverse impacts on the downstream river environment and the groundwater recharge operation. The Main San Gabriel Basin Watermaster, the project sponsor and one of several agencies interested in the success of groundwater recharge, was interested in seeking an alternative solution to sluicing. The project complexity was not limited to technical difficulties. In the process of doing this project, the students learned how to manage a project from inception to completion, work as a team, perform independent research, design experiments, analyze data, draw conclusions, write a seamless joint report, and present the findings to diverse audiences. There were numerous challenges along the way. The students experienced periods of: optimism when they first started; frustration as they realized how complex it was; enthusiasm when they had a handle on the issues and focused on a specific approach; elation when they finished data analysis and were able to draw a conclusion and make a recommendation; again frustration during report writing; satisfaction and relief when the report was completed; and finally gratification when they presented their results at public meetings. Throughout these periods of vicissitudes, the faculty advisor and an industry sponsor were with the students constantly to provide encouragement and directions. The students learned that one could not always expect textbook cases in the real world. They not only had to know all the fundamentals they learned at school, but also had to be able to figure out how to apply this knowledge in real cases that might not be as ideal or clearly defined as in a textbook. They also had to be able to learn new things, in this case sediment transport and sediment dredging, on their own. The hydraulics of sediment transport is very different from that of water. With this experience, the students were well prepared to take on any complex project and tasks that they may encounter upon graduation on a job or at graduate school.

Sediment Management Project

Sediment in Morris Dam, which is located on the San Gabriel River in Los Angeles County, California, has filled up one third of the reservoir capacity. The sluicing method was selected to remove sediment from the reservoir. First, the reservoir to be sluiced was drained. Next, the drained reservoir was subjected to low flows from upstream sources. These flows cut through the reservoir floor and flowed down to the open pipes of the dam. Sediment from the empty reservoir's floor was pushed into the flow and washed through the dam and into the riverbed downstream. Workers were required to keep the outflow gates clear of debris continuously for 24 hours a day. In addition, heavy machinery was used in the riverbed to build and maintain levees that were constructed to confine the sediment flows within a small portion of the riverbed. During sluicing, the reservoir was not available for flood control.

Soon after the sluicing began, it became apparent that the levees constructed in the riverbed to confine sediment material were inadequate. The levees, which had been designed with a 20-foot width, were constructed using materials in the riverbed with an actual width of 50 to 100 feet. The sediment began to accumulate and the levees quickly failed. Sediment spread over the entire river bottom. To solve this problem, heavy machinery was used in an attempt to maintain the confining levees and to keep the riverbed clear of sediment. Between certain reaches of the river, the sediment accumulated to a depth of more than six feet, deeper than the tires of the heavy machinery. The crews stopped trying to maintain the levees due to safety considerations. Sediment material spread all over the riverbed that was counted on for groundwater recharge.

Several forms of research were used to gather specific information about the sediment problems in reservoirs on the upper San Gabriel River and information in general on sediment problems in reservoirs, including the effects of sediment on percolation and methods of removing and transporting sediment. The team started out with researching studies previously conducted by LACDPW and its consultants, and met with LACDPW staff to understand the problem and to become familiar with the project. The team researched publications and on-line databases in the library and on the Internet. After an extensive literature search, the team concluded that very limited information was available on certain topics, namely the effect of sediment deposition on percolation, use of dredging equipment in a reservoir, and hydraulics for slurry transport. The search expanded into contacting experts, whose names were found through various sources, on related topics. The team further conducted several field trips to perform in-depth investigations on the physical parameters of the project. The information search tasks were labor-intensive and time-consuming. After extensive research, the team found a relevant book entitled "Reservoir Sediment Handbook", by Gregory K. Morris and Jiahua Fan. However, information on the effect of sediment deposition on percolation was not found. The team contacted the author, Gregory Morris, in Puerto Rico and learned that no such information is available anywhere. The team then decided that it would be necessary to design and perform some laboratory or field-testing in order to obtain the necessary data.

A number of laboratory tests were conducted to determine the potential effects of sediment deposited along the channel on groundwater recharge. The following analyses were performed: Sieve Analyses, Hydraulic Conductivity, and Infiltration of Fines and Turbidity Tests. The groundwater analyses were performed on samples of native soils acquired from the riverbed and on samples of sluiced sediment from Morris Reservoir. Test results indicated that percolation rate was reduced due to the sediment deposit. The turbidity initially increased drastically, then decreased slowly as time went on. Because the turbidity and flow decreased over time, the fine-grained material or sediment probably migrated a few inches into the underlying soil. Therefore, the adverse effect of sediment on the percolation rate may be reversible and can probably be corrected. The sediment on the riverbed surface could probably be removed naturally by winter storm scouring, flushing the sediment within the river channel, or by traditional methods of excavation such as earth moving equipment.

Slurry Line Alternative. Approximately 1.3 million cubic yards of sediment must be removed yearly from Morris Dam in order to maintain the current available storage for flood control. According to the sieve analysis, nearly 89% was less than #200 mesh (0.075 mm) and the remaining was distributed between #4 and #200 mesh. D_{50} was estimated at 0.041 mm (0.0016 in.). Therefore, the design velocity for slurry transport was based on these grain sizes. Durand–Condolios' limiting deposit velocity equation was used to determine a transition velocity that separates the suspended heterogeneous sediments from the moving bed regime. To avoid blockage, the pipeline velocity must be greater than the limiting deposit velocity. The equation is

$$V_{LD} = F_L \sqrt{2gD\left(\frac{\rho_S}{\rho_W} - 1\right)}$$ Where

V_{LD} – limiting deposit velocity
F_L – constant depending on grain size
g – acceleration due to gravity
D – pipe diameter
ρ_s – density of solid particle
ρ_w – density of water
C_V – volumetric concentration of sediment

The Durand–Condolios equation includes a constant, F_L, based on different sediment concentrations and grain sizes. For a grain size of 0.075 mm, the constant is about 0.8 regardless of the sediment volumetric concentration. The limiting Deposit Velocity calculated by Durand-Codonlios equation for various pipe diameters is shown in Table 1.

Durand's Equation is used to calculate the head loss for slurry conditions by incorporating sediment concentration, particle size, specific gravity of particle, and pipe diameter. Durand's Equation is noted:

$$\frac{i - i_w}{(C_v)(i_w)} = 81\left[\frac{(SG_s - 1)gD}{V^2\sqrt{C_D}}\right]^{1.5}$$

where i = friction loss for slurry, feet of water per foot of pipe (ft/ft)

i_w = friction loss for water, feet of water per foot of pipe (ft/ft)

C_v = volumetric solid concentration in slurry

C_D = drag coefficient of particle settling in fluid of infinite extent

SG_s = particle specific gravity

g = acceleration due to gravity (32.17 ft/s^2)

D = pipe diameter (ft)

Table 1-- Durand-Condolios Limiting Deposit Velocity

Pipe Inner Diameter		Limiting Deposit Velocity d=0.075-mm	
in.	mm	ft/s	m/s
6	152	5.8	1.78
10	254	7.5	2.29
12	305	8.2	2.51
14	356	8.9	2.71
16	406	9.5	2.90
18	457	10.1	3.08
20	508	10.6	3.24
24	610	11.7	3.55
SG_{SOLID} = 2.65		F_L = 0.8	

Several possible scenarios were considered in the design of the slurry pipeline based on a sediment removal rate of 1,300,000 yd^3/yr with a sediment SG of 2.65. Various operational schemes were studied in terms of numbers of weeks per year, number of days per week, and number of hours per day. The selected scenario was continuous operation for 37 weeks per year using a 14-inch ID high-density polyethylene pipe. A 15% C_v was selected. The calculated flow rate, velocity and head loss are shown in Table 2.

Table 2—Slurry line Design

Days per week in operation	7
Hours per day in operation	24
Inner pipe diameter D (in.)	14
Hazen-Williams Friction Coefficient C	145
Slurry flow rate (ft3/s)	10.5
Slurry flow rate (gpm)	4700
Velocity (fps)	9.8
Friction loss for water (ft/1000ft)	17
Friction loss for Slurry (ft/1000ft)	56

Concrete Channel Alternative. A concrete sluice channel was designed and proposed as an alternative to replace the earthen berms that had failed during the sluicing process. To determine the required dimensions, the HEC-RAS program was used to model the water surface profile in a proposed lined channel for portions of the riverbed between Morris Dam and Santa Fe Dam which is located approximately five miles downstream of Morris Dam. The channel would be trapezoidal in shape, approximately 8 ft. wide at the bottom and having 1-to-1 side slopes.
According to the results obtained from the HEC-RAS program, the channel velocity ranges from 7 to 10 fps and reaches a velocity of 25 fps near the drop structures. This channel resulted in adequate suspension of the sediment particles. However, there are limitations to the accuracy of the analyses. The HEC-RAS program models surface profiles of water – not the slurry that actually exists during the sluicing process – and does not account for the possible deposition of sediment along the channel.

Dredging Alternative. Two sediment removal methods were evaluated. In the dry excavation method, the reservoir is drained of water and the sediment is removed under dry conditions. In the wet excavation method, the sediment is removed while water is in the reservoir. Sluicing is a form of dry excavation. After draining Morris Reservoir, heavy equipment was used to push sediments into a low-flow stream, which then conveyed the sediments into the streambed below Morris Dam. This method proved to be cost-effective; however, the reservoir would be out of operation, therefore, voided its flood control capability. If a storm had occurred during the sluicing operation estimated damage for flooding downstream communities would have been close to $3 billion. In addition, other problems should be resolved in order to continue the current sluicing project. Wet excavation is the removal of sediment while the reservoir remains full or partially full of water. Several types of dredges exist, with mechanical and hydraulic dredges being the most common types. Mechanical dredge uses buckets or ladders to scoop material from the bottom of the reservoir and lift it to the surface with minimal amounts of water. Hydraulic dredge uses suction, often with jets or cutters, to transport material to the surface or to a point of placement. Both are used in much larger operations. Dragflow pump, a cable-suspended dredge pump by Hager Pump, appeared to be most suitable for the intended application.

Estimated Costs. The projected total cost of removing sediment from the reservoir by dredge pump is approximately $2.48 per cubic yard. The estimated cost of transporting the sediment downstream for disposal is approximately $1.60 per cubic yard using a slurry pipeline and approximately $1.24 per cubic yard using a concrete-lined channel. The estimated cost of a dredge pump and slurry pipeline system is approximately $4.08 per cubic yard. The estimated cost of a dredge pump and lined channel system is approximately $3.72 per cubic yard.

Project Conclusions and Recommendations. Based on this preliminary study, a combination of a dredge and a transport system could be constructed at reasonable costs and would allow year-round operations and maintain constant flood control capabilities. Therefore, the recommendation was that LACDPW pursue further investigations into dredging in combination with slurry pipeline or lined-channel. Should the LACDPW decide to continue sluicing, the recommendation would then be to add a lined channel to contain the sluiced material within a small portion of the existing riverbed.

Challenges

Project Development and Management. This project involved a very difficult real problem the agencies have been struggling with for decades. Many studies have been done previously and no ideal solution has been found. It took the students a considerable amount of effort just to understand what the project was about. They researched previous documents, contacted various people as to why sluicing was implemented, visited dam sites and along the riverbed, and investigated the problems associated with the sluicing operation. The amount of information was overwhelming. Once they had a good understanding of what the problems were, they sought solutions through research and, when no existing information was available, conducted tests and collected original data. The students divided responsibilities in accordance with the strength and availability of each in order to improve team efficiency and effectiveness. Finding time for project meetings and performing project work was a challenge for all. There were regular 2-hour weekly meetings and unscheduled task meetings. The team relied on E-mail and phones for communication during other times. Most students were taking 16 units or more of schoolwork and had part-time employment working 15-20 hours a week. Both the faculty and industry advisors attended all regular meetings and some tasks meetings. The role of the advisors was to keep the students motivated, focused, on schedule, and to steer the team away from dead ends.

Technical Complexity. This project dealt with sediment management where each case was unique and very little information was available in the literature. The most useful information was found in reports prepared by engineering firms for LACDPW. Unfortunately, that was the only perspective available and at times, the reports were unclear as to how the results were drawn. The team performed its own tests that involved collecting samples downstream of the dam in the riverbed and performing tests in department laboratories. The access to sampling sites was difficult and the lab testing was time consuming. It also took a while to calibrate the permeameter before meaningful results could be obtained. The analyses for slurry transport required estimates on transport velocity and friction loss. Duran-Condolio's equation was used for transport velocity and Durand's equation was used to calculate friction loss. Both are complex equations not normally covered in undergraduate civil engineering curriculum.

Report Writing and Public Speaking. Writing a report was not easy for most of the students. Writing a joint report was even more challenging. Each student had a different level of competency as well as style of writing. Trying to link fragmented parts of writing into one report was very challenging. It took numerous revisions to smooth out the report. This project also provided an excellent opportunity for students to improve their public speaking skills. During the last quarter of the project, students did weekly presentations. Each presentation was critiqued at the end of the meeting. PowerPoint material was updated constantly. The improvements were very significant. In the end, the students were very confident and well prepared for their presentation in public meetings. The questions posed to the students in these public meetings were very challenging. The questions from engineering professionals were tough but fair, and the students were able to answer effectively. Questions from environmentalists, who had very different perspectives or objectives, were very challenging.

Concluding Remarks. The sediment management project proved to be a highly successful vehicle for preparing seniors for their careers. They had accepted all the challenges and successfully completed a very complex project. In the process, they have gained perspective of a real world project; and improved their project analysis capability, report writing and public speaking skills. Other benefits included providing the agencies with a fresh project perspective and increasing the visibility of the university in the community.

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