Visualization Requirements of Engineers for Risk Assessment of Embankment Dams

Varun Kasireddy[a] , Semiha Ergan[a] and Burcu Akinci[a]

[a] Department of Civil and Env. Engineering, Carnegie Mellon University, Pittsburgh, PA, 15213, USA
Corresponding Author E-mail: varunkasi@cmu.edu

Abstract -

Aging infrastructure in the US has gained quite a bit of attention in the past decade. Being one type of a critical infrastructure, embankment dams in the US require significant investment to upgrade the deteriorated parts. Due to limited budgets, understanding the behavior of structures over time through risk assessment is essential to prioritize dams. During the risk assessment for embankment dams, engineers utilize current and historical data from the design, construction, and operation phases of these structures. The challenge is that during risk assessment, various engineers from different disciplines (e.g., geotechnical, hydraulics) come together and how they would like to visualize the available data sets changes based on the discipline-specific analyses they need to perform. The objective of this research study is to understand the discipline specific visualization needs of engineers from US Army Corps of Engineers (USACE) who are involved in risk assessment of embankment dams when they deal with large set of data accumulated since the inception of dams. The requirements were identified through a three-phased research approach including interviews with engineers who are regularly involved in risk assessment processes, a card game and review of standards and published work on risk assessment of embankment dams. The findings suggest that visualization of the dam layout, components and geometry within 3D settings overlaid with sensor data (which could be queried based on engineers' discipline specific needs) and data analytics results provide a better flexibility to engineers to understand the risk associated with potential failure modes.

Keywords -

Mining; Built Infrastructure; Human Factors; Embankment Dams; Visualization; 3D modelling; Risk Assessment

1 Introduction

Embankment dams, particularly, the aging ones are prone to failure with progressing time. Various types of failures, including internal erosion, sliding due to loading and overtopping, exist for an embankment dam. Many dams have already received a “poor” rating as per the grade card released by ASCE recently [1]. Most importantly, these dams are an integral part of a prospering economy, and directly concern the lives of a large percentage of population living nearby. To repair and rehabilitate all of those dams are simply not possible due to budget constraints, and hence dams that require immediate remedial actions need to be identified and prioritized. One practical approach for this prioritization is through risk assessment, which includes the assessment of these dams periodically for the level of risk of failure and the magnitude of economic and life causalities associated with such a failure, and act accordingly.

Risk assessment process is an interdisciplinary process and involves engineers of various disciplines like Geotechnical Engineering (GT), Geology (GE), Hydraulic Engineering and Hydrology (H&H), and Structural Engineering (SE). Also, risk assessment activities are typically carried out in different frequencies and granularities. Examples include daily monitoring, which is performed on the daily data collected on the dam to detect changes in readings overtime; periodic inspection (PI), which is conducted every five years in a detailed manner including historical data, and periodic assessment (PA), which is conducted every ten years with interdisciplinary parties. Currently, during these sessions, the multi-disciplinary team of engineers has access to different types of information, such as design, construction and operation information and accesses them through digital or hard copy documents. Collecting the required information and processing/analysing the document based information are resource and time intensive [2].

Unique challenges that engineers face during risk assessment include (a) bringing a spatial context to the sensed data from piezometers, inclinometers, survey monuments and weirs, (b) understanding the behaviour of dams over time by correlating several parameters about dams (e.g., evaluating pool elevations with respect to piezometer readings, piezometer readings with respect to their station locations, piezometer tip elevations with respect to soil layers etc.). While data collection and processing efforts are preliminary data stages, it is the data visualization stage that plays a vital role in understanding the valuable information concealed inside the data. As data can be represented in different forms, and stored in multiple formats, it is important to understand which form is the most useful for the end users of the data, i.e., dam engineers in this case, to aid in the risk assessment process. For this purpose, it is necessary to identify the engineer's visualization requirements.

Engineers develop various artefacts to keep track of the correlations in mind, such as correlation plots, cross section layouts, piezometer locations on a plan view, lithology plans showing bore-hole locations and properties. Current tools and artefacts used by engineers do not enable them to perceive the data and correlations between them through views that can be generated flexibly based on how the engineers would like to look at the data. The artefacts are static and are not always capable of correlating the parameters at a glance [3]. Likewise, our initial interactions with engineers during a risk assessment session showed that the visualization requirements and corresponding modes of visualization vary as per the background of an engineer. For example, geotechnical engineers require to look at how different rock types are spatially distributed over the dam site and laboratory rock tests reflected as such. On the other hand, geologists intend to look at the same data in a layer-wise manner, and prefer to be able to turn on/off different rock-type layers within the same 2D/3D visualization window. Consequently, this mandates the requirement of a flexible visualization paradigm to ensure effective and efficient perception and comprehension of the data.

Within the context of this paper, the authors provide the details of the findings on identification of discipline specific visualization requirements of engineers needed during risk assessment of embankment dams. The authors describe the related background research (Section 2), detail the three-pronged research methodology adopted in this study (Section 3) and give details of the findings (Section 4). The paper concludes with recommendations and possible future directions.

2 Background Research

Several studies in the literature have been done in relation to usage of various forms of visualization to aid the dam risk assessment process. Harnessing different modes of visualization, i.e. 3D and 4D,to present different types of information from disparate sources enhances the ability to absorb the content, as well as the ease of its access, when required [4].

In relation to 3D and 4D visualization, researchers typically represented dam body and its features in 3D, while some features which varied over time were simulated in a 4D environment. Studies focused on highlighting different parts of the dams to be visualized. Such studies include visualization of surface and groundwater features for hydraulic erosion for various types of dams and levees [5], and visualization of geometric surfaces, lithological and hydraulic level properties [6]. Such information visualization has also been performed over web-based platforms to facilitate quick feedback and information dissemination during multi-disciplinary meetings with participants from disparate locations [7].

Besides these, some researchers used GIS paradigm to model, simulate and visualize dam-specific features, for example, Serre et al. [8] modelled levee performance to help in planning inspections, maintenance and repair work; and Qi and Altinakar [9] for floods. Likewise, GIS and geo-databases were integrated to represent rich contextual information, with Shumilov & Breuing[10] specifically working on the integration of GIS and geo physical 3D modeling tools. Apart from 2D- 3D visualization of behavior of dam and site features and characteristics over time, engineers also prefer to easily access past construction photos and reports, in order to understand what features of the dam have changed over different phases of its life cycle.

One of the main differences between the previous studies on 2D-3D-4D visualization applied to dam risk assessment and the study presented here is the way visualization is utilized. The previous studies did not focus on developing a holistic understanding of the ways engineers would like to look at the data given their engineering discipline and developing visual forms to enable those. The study presented in this paper focuses on characterization of such visualization needs to better serve engineers during their decision making processes while assessing risk levels of dams.

3 Research Objective and Methodology

The main objective of this study is to understand the requirements of the engineers with regard to their preferences in visualizing information while performing embankment dam risk assessment activities for a dominant failure mode. This paper provides findings in relation to internal erosion. Internal erosion, in particular, is complex to understand, and can even be triggered by normal day-to-day operations without a high intensity event like frequent high pool elevations. Internal erosion is also a major cause of failure of embankment dams [11], and hence was the reason to focus on internal erosion in this study. Previous literature on requirements elicitation (Wiegers [12]; Gould & Lewis [13]) suggests that the most productive approach to accumulate and analyze requirements for a specific task is to determine use cases and build prototypes with varying levels of details while utilizing user feedback at each stage of the prototype development process. The research team used a similar approach that incorporated a multi-phased requirement elicitation and case analysis to interact with engineers and document their visualization requirements during risk assessment process.

A three phased approach is used in this study to identify and validate the visualization requirements of engineers drawn from different disciplines. These phases are described in details in subsequent sections:

3.1 Phase 1: Requirements Elicitation through Systems Investigation and Interviews

In this phase, the research team conducted face-to-face unstructured interviews with engineers involved in risk assessment processes, and investigated the information systems used by the engineers to understand different views/figures currently generated with these systems. The larger goal of this phase is to compile a preliminary list of visualization requirements which would constitute an initial list of use-cases for a more-structured elicitation and validation of requirements. 15 engineers from different disciplines, as detailed in Table 1, participated in this study. Majority of these engineers were experienced engineers who have been involved in risk assessment processes for several embankment dams.

Several systems are currently used by engineers to store, access, and visualize the collected sensor data. They gave integrated plotting, reporting and GIS-linking capabilities, based on predetermined templates. During the study, these systems have been evaluated as part of the preliminary analysis so that the preliminary list of visualization requirements could be enumerated and that they could be communicated and discussed during the Phase I interviews with the engineers.

The primary focus of the interviews during Phase 1 was to capture discipline specific visualization requirements without delving too much into the process of extracting only those requirements which are relevant to the particular failure mode being assessed in this study.

Table 1 Overview of participants of the study

Phase	Number of participants	Years of Experience	Discipline (s)*
I	7	10-32	H&H, GT, SE, GE, CE
II	5	13-37	GT, H&H, GE, CNSTR, SE
III	3	4-16	H&H, CE

*H&H: Hydraulic Engineering and Hydrology; SE: Structural Engineering; GE: Geology; GT: Geotechnical Engineering; CE: Civil Engineering; CNSTR: Construction Engineering

These preliminary findings were also useful to determine how engineers would like to visualize different dam features, and also to remove the ambiguity, if any, in the meaning of the terms from the perspectives of each engineering discipline.

3.2 Phase 2: Requirements Elicitation through a Card Game, Examination of Standards/Guidelines and Case Documentation

Unlike the previous phase, wherein the requirements were collected in a generic sense, in this phase, the focus was particularly on assessment of internal erosion problems. In this regard, a card game was designed to expand the initial findings of the Phase I. Additionally, the team investigated standards and publications related to internal erosion assessment; and other risk assessment documentation available for three selected dams. The main strategy here is to corroborate the visualization requirements based on the analysis of multiple sources of information, i.e., through triangulation. Triangulation ensures the generality of the findings.

To approach capturing the discipline specific visualization requirements of engineers, a card game was designed to be used with accompanying scenarios. The card-game included pile-of cards, and each card represented an information item that an engineer might be interested in knowing to understand the behaviour of a dam. Piles included several categories such as information about instrumentation, embankment features, historic reports, field tests, and drawings. Among each pile of cards, blank note cards were placed to accommodate the situation in which a participant asked for information that was not already represented in the pile of cards. Given a scenario, engineers requested information to assess the risk level for internal erosion and define how they would like to visualize that information.

As part of the triangulation efforts, the research team examined various engineering guidelines/manuals like engineering manuals (EM), engineering regulations (ER). In addition, for three selected embankment dams, the research team examined the plots and visualization approaches used to depict or highlight identified facts about the dams in previous risk assessment reports.

3.3 Phase 3: Requirements Validation through Prototype Development and Face Validation

The main tasks carried out in this phase to validate the requirements identified in the above two phases included development of a functional prototype integrating all visualization requirements, and taking user feedback regularly through showing each identified and implemented view. The prototype was developed using an object-oriented language and enabling renderings of rich 2D-3D graphics. With this prototype, it was possible to do face validation with the users in terms of pinpointing any discrepancies between what the research team interpreted vs what the users actually asked for.

4 Research Findings

The findings are presented in terms of what has been identified as visualization requirements through the requirements elicitation approaches and then how the findings were implemented in the functional prototype.

4.1 Identified Visualization Requirements

The research team identified a total of 42 unique visualization requirements based on the research methodology outlined in the previous section. They have been tabulated in Table 2 based on the engineering disciplines and the overarching categories of visualization. Observations from Table 2 reveal that some of these discipline-specific requirements overlap with those of other disciplines, and the details of the same are discussed in the subsequent paragraphs. For the convenience of the reader, the authors have highlighted the overlapping requirements across different disciplines in bold font in Table 2. As a whole, Table 2 gives an idea of how visualization requirements vary with engineers from different backgrounds for the case of internal erosion risk assessment.

The distribution of the findings with respect to the engineering disciplines is not equally distributed. We can clearly understand from Table 2 that 78% of the total unique visualization requirements were provided by geotechnical engineers and 35% of the requirements were provided by geologists, with overlapping requirements between groups. They were followed by Hydraulic engineers/Hydrologists (H&H group), who contributed to 16% of the total requirements. Similar in scale to the H&H group, structural engineers contributed only 14% of the total. The reason for having a wider set of requirements stated by geotechnical engineers and geologists is due to the scope of the problem being internal erosion, which falls more to the domain of geotechnical engineers. Also, since the scope of this study was limited to embankment dams in which structural features are minimal in comparison to other dam types such as the concrete dams, having a less number of requirements defined by structural engineers is expected.

When Table 2 is analysed in terms of commonalities of visualization requirements based on engineering disciplines, it was observed that only 14% of the total 42 requirements such as geometrical information about dams; pre-existing structures; and reservoir pool and tail water elevations; were of interest to the engineers to look at collectively from all disciplines. There was a consensus among engineers regardless of their disciplines regarding certain visualization requirements. For example, all engineers preferred to have site plans for pre-existing features, which are important to know about for internal erosion assessment, around the dam site in 2D views. Similarly, the opinion was unanimous as far as the representation of dam geometry and information related to it in a 3D view. They also would like to have additional tools to be able to export different cross sections and plan views, and to turn on and off different layers (e.g., instrumentation, zoning, soil layers, pre-existing site plan, etc.). All disciplines also underscored the importance of visualizing the zoning within the dam (e.g., cross-hatching, colour, etc.) as well as the reservoir and tail water information. Here, all the engineers prefer to access the raw reservoir pool and tail water elevations and look at the related plots in a single view. In the same context, engineers would also like to be able to visualize water levels and flows over time (i.e., a 4D simulation of the water level on 3D dam geometry). In addition to these, the research team studied and identified that some of the requirements i.e., instrumentation information and readings provided within 3D settings and geotechnical and geologic information provided in plan views were common to at least three engineering disciplines.

Though there are overlaps in the visualization requirements among engineer disciplines, the percentage of overlap varies with the discipline specific visualization requirements. For instance, from Table 2, it is evident that most of the 3D visualization requirements of geotechnical engineers overlapped with the requirements of the engineers from other disciplines.

The overlapped features include turning on/off various layers of the information on the 3D model as well as visualization of instrumentation information (e.g., location, tip elevation etc.,) and instrumentation readings within the 3D settings. In contrast to that, the requirements of geologists do not have many overlaps with engineers from other disciplines.

Specific to the H&H group, hydraulic engineers were interested in the features enabling the visualization of regional rainfall inundation map, Possible Maximum Flood regional map, Hydro Meteorological Report-51 i.e. a probable maximum precipitation document, and the 3D view of the dam geometry. Furthermore, they also expressed interest in accessing tail water, pool elevation and reservoir inflow characteristics in a tabular form. Besides that, they also wanted to look at the hydrologic loading data for coincident pools for seismic PMFs, hydrologic loading data for flood events, inflow-volume-duration-frequency curve [1-7] day computed probability, pool-frequency, and pool-duration curves.

Incidentally, the visualization requirements of the structural engineers have a good overlap with those of the H&H group as far as the H&H tabular data is concerned. They have additional requirements for 3D visualization of the dam instrumentation and the site plan. On the other hand, the interests of civil engineers lie in the availability of instrumentation data - in the form of tables, and 3D geometry of the dam.

4.2 Implementation of Visualization Requirements in the Functional Prototype

The prototype was developed in an iterative and a participative manner, in which the opinion and feedback of the end users regarding the functionalities incorporated in the prototype, visual requirements implemented, and usability aspects, were regularly taken to customize existing features and also add new features if necessary. Initially, a view for accessing and displaying instrumentation meta-data was implemented along with a 2D data viewer for static 2D plots (i.e., requirements 8, 10, 16 and 17 in Table 2). A 3D model viewer was built in to the model and integrated with several required data to display contextual information about dam features and instrumentation data were added (i.e., requirements 25, 26, 29, 30, 33 n Table 2). In the next phase, querying capabilities for instrumentation data were incorporated (i.e., requirement 34 in Table 2). 2D data viewer was augmented with a dynamic time slider to visualize variation of readings over time (i.e. requirement 9 in Table 2), based on the feedback of engineers. In the following phases, views for bore-hole test results (i.e., requirements 19-20 and 36-37 in Table 2), document/photo access panels and image display capabilities were added to the prototype (i.e., requirements 1-7 and 11-15 in Table 2).

Discussing all the features implemented in the prototype is out of scope of this publication; simply due to their sheer number and the space restrictions. However, some of them are detailed below:

Implementation for visualization of piezometer meta-data and time-series readings

In relation to instrumentation data visualization, piezometers were the commonly referred instrument type to know about for internal erosion assessment. Engineers wanted to select different piezometric zones of influence within the 3D dam body and select the desired piezometers within them to examine their meta information. Meta-data and additional information to be specified for each piezometer included tabular and plotted piezometer data over time with respect to pool elevations, instrument location and tip elevation with respect to soil layers and stations in the dam, as well as piezometer influence zone in 3D phreatic surface (i.e., requirements 9, 10, 33 in Table 2). In addition to this, engineers would like to compare different piezometers using the querying functionality and plotting their readings over time along with the pool elevation variation using the time slider; and in the form of time series data were implemented– as shown in Figure 2.

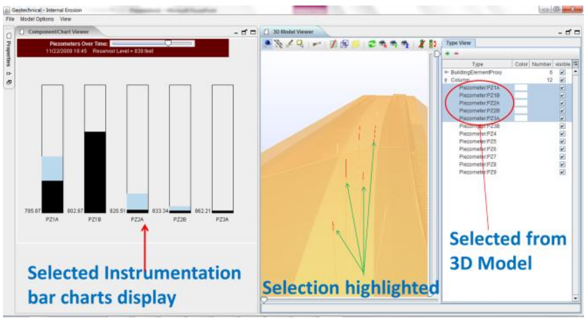

Figure 1. A snapshot showing that different instruments can be selected from 3D model interface

Implementation for visualization of testing data such as boring logs and rock tests

Within testing data, “boring logs” is one of the frequently used words in the interviews with most of the geotechnical engineers and geologists (i.e., requirements 20 and 37 in Table 2). Important features implemented, concerning boring log information, are meta-data display of any selected bore hole inside a data panel; and display of different soil strata within each boring log. As engineers also showed tremendous interest in the ability to query for different bore holes based on a certain criteria, advanced query docking frame has been implemented for customized comparison, and here, users are able to put different bore-holes side-by-side and view their strata properties, and meta information and other related information(as shown in Figure 3).

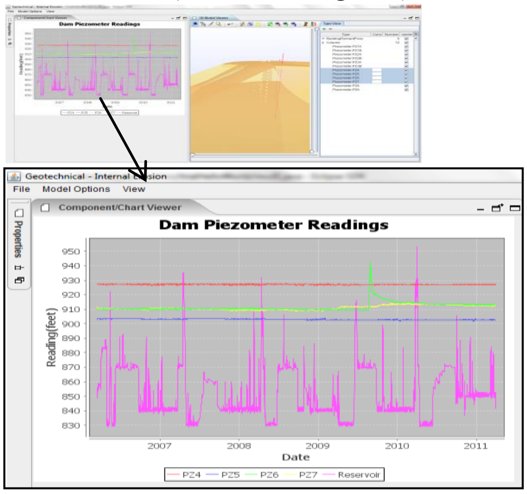

Figure 2. A snapshot showing that a time series of selected piezometers

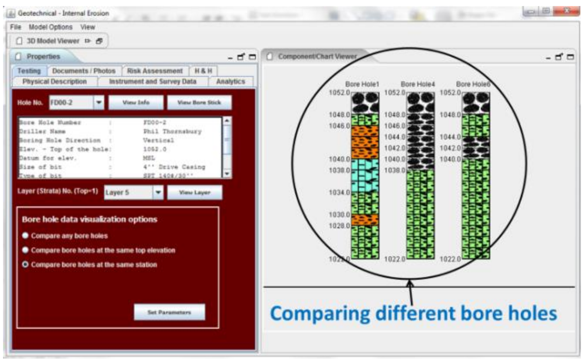

Figure 3. A snapshot showing that different bore holes can be compared (we can see different strata layers of each bore hole in this figure)

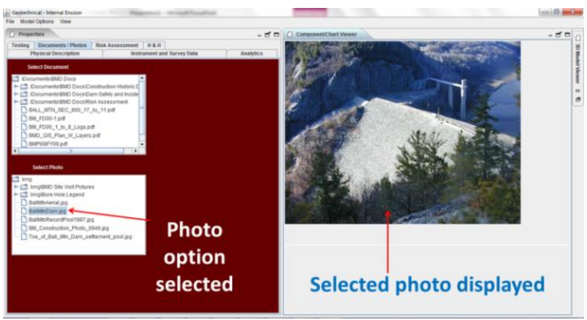

Figure 4. A snapshot is showing various documents and photos can be stored and accessed from the integrated prototype

Implementation for visualization of documentation and construction history photos

Most of the dams have been constructed many years ago and they have lot of paper documentation concerning its construction history, repairs, site instrumentation, standards etc. With time, it becomes very difficult to retrieve particular old documents, say, if needed for a risk assessment process, or even for the perusal of the project engineers. Hence, engineers wanted an internal document indexing system within the prototype to drag and drop digitized files and photos and to be able to retrieve these indexed files quickly within the same interface, whenever needed. The implementation of this feature is shown in Figure 4, wherein a user selected a photo from the file index panel, and it is being displayed in the adjacent docking panel.

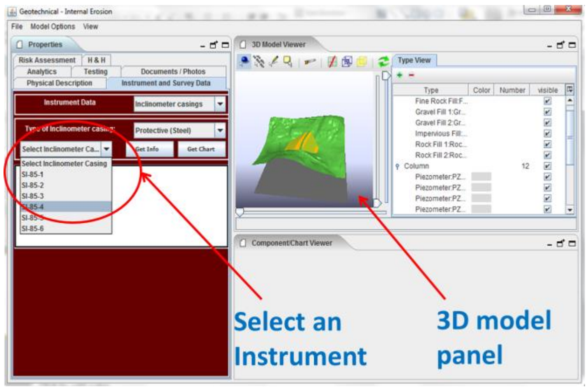

Figure 5. A snapshot showing 3D model panel

5 Conclusions

Visualization empowers engineers to conveniently visualize, integrate and accurately interpret the data from disparate sources. For internal erosion risk assessment in embankment dams, engineers from several disciplines require dam information to be viewed from different perspectives. This study provides the findings of visualization requirements of engineers involved in risk assessment processes while looking at historical dam information.

While the engineers would like to be able to use the current methodologies they are using to visualize static data related to embankment dams, they desire for an advanced 3D visualization paradigm that allows the end users to at least import different cross sections and plan views; turn on and off different information layers concerning instrumentation and other site plans; and simultaneous comparison through querying and visualization of multiple boring logs, piezometers, and monuments.

The findings from this study suggest that engineers would like to visualize the dam layout, components and geometry within 3D settings overlaid with sensor data, and querying capabilities in order to get a better flexibility to understand the risk associated with potential failure modes. Armed with this flexibility, they can be more effective and efficient during risk assessment sessions, and can contribute to better dam maintenance decisions.

Future work can include putting efforts to quantify the value of using such visualization tools with engineers through scenarios from a specific dam for assessment of internal erosion. Among the instruments mainly used in the data collection tasks at the dam location, the research team focused mainly on the piezometers in the risk assessment process for the current study. In the future, other available instrumentation and their readings could be investigated to understand internal erosion risk and risk due to other failure modes in a holistic manner.

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References

[1] American Society of Civil Engineers "Dams". America's Infrastructure Report card 2013. On-line: http://www.infrastructurereportcard.org, Accessed: 27/01/2014.

[2] Shaffner, P.T. Geologic Data and Risk Assessment; Improving Geologic Thinking and Products. *In Proceedings of the United States Society on Dams Annual Meeting and Conference*, pages 545–570, San Diego, USA, 2011.

[3] United States Army Corps of Engineer. Improving Safety Monitoring for Embankment Dams, CMU, Pittsburgh, PA, USA, 2011-12.

[4] Pantea, M.P., Hudson, M.R., Grauch, V.J.S., and Minor, S.A., Three-dimensional geologic model of the southeastern Española Basin, Santa Fe County, *New Mexico: U.S. Geological Survey Scientific Investigations Report 2011–5025*, 17 p, 2011.

[5] Chen, Z., Stuetzle, C. S., Cutler, B. M., Gross, J. A., Franklin, W. R., & Zimmie, T. F. Analyses, simulations and physical modeling validation of levee and embankment erosion. *Geo Frontiers*. 2011.

[6] Dominguez-Acosta, M., Granados-Olivas, A., & Hibbs, B. Computer based three-dimensional modeling of Hydrogelogic units in the Transboundary Ciudad Juarez-Paso Del Norte Region, 2011.

[7] Lemke, C., Innovation through technology. *Solution Tree Press*, 2011.

[8] Serre, Damien, Laurent Peyras, Rémy Tourment, and Youssef Diab. Levee Performance Assessment Methods Integrated in a GIS to Support Planning Maintenance Actions. *Journal of Infrastructure Systems* 14.3 (2008): 201-13.

[9] Qi, Honghai, and Mustafa S. Altinakar. A GIS-Based Decision Support System for Dam Break Flood Management under Uncertainty with Two Dimensional Numerical Simulations. *Journal of Water Resources Planning and Management*, 2011.

[10] Shumilov S., and Breunig M. Integration of 3D Geoscientific Visualization Tools with help of a Geo-Database Kernel. *6th EC-GI &GIS Workshop "The Spatial Information Society - Shaping the Future Lyon",* France, 28-30 June, 2000.

[11] Frank Blackett. Potential Failure Modes for Piping and Internal Erosion. On-line: http://www.oregon.gov/owrd/SW/docs/dam_safety/M6_Blackett_Internal_Erosion.pdf Accessed: 29/01/2014.

[12] Wiegers, K. *Software Requirements*, 2nd edition, Microsoft Press, Redmond, WA. 2003.

[13] Gould, J. & Lewis, C. Designing for Usability: Key Principles and What Designers Think. *Comm. of the ACM* (28), pp. 300 – 311. 1985.

[14] Tulke, J., Tauscher, E., Theiler, M., and Thomas, R. Open IFC Toolbox. On-line: http://www.ifctoolsproject.com Accessed: 30/08/2013.

Table 2. Identified Visualization Requirements – Visualization Mode wise

Discipline	Visualization Requirements	
	2D visualization mode	3D visualization mode
Geotechnical	***1. Site Plans for pre-existing structures*** *2. Drawings showing the geometry to compare the as-constructed drawing for dam body* *3. Drawings with zoning, thickness and geometrical properties within the dam body* *4. Cross-sections showing the geometry of the spillway* *5. Contour diagrams of the channel and topography* *6. Current photos and change of vegetation over time* *7. Site Plans* ***8. Tabular data of reservoir pool and tail water elevations*** *9. Top 10 events performance and ratings for the reservoir and tail water* *10. Time history plots of reservoir level per cross section* *11. Geologic maps* ***12. Geo technical and geologic drawings*** *13. All drawings related to spillways* ***14. Construction historic data reports*** ***15. GIS map*** ***16. Instrumentation tabular data and plots*** *17. Tabular data and plots showing the deflection in the instrumentation* *18. Full laboratory soil testing report including values* *19. Soil test values portrayed by soil horizon and depth which has its won hatching style*	***25. Dam geometry*** *26. 3D model with renderings of the pre-existing structures* *27. Animation for reservoir and tail water* *28. 3D Immersive foundation model* *29. 3D model where can export cross sections or play views with layers turned on or off* *30. Full rock testing report shown spatially by rock type* ***31. Simulations of different scenarios as consequence information*** ***32. 3D view of instrumentation and readings*** *33. Piezometer in 3D phreatic surface showing the influence zone for the user defined periods* *34. Comparison of the piezometer cross sections according to their elevation and material type* *35. Profile of dam with lines to show how it has settled* *36. Visualization of total site boring plan* ***37. 3D visualization of side by side boring logs adjusted for elevation enables engineer to click and obtain the boring log report***
Geologist	• ***Site Plans for pre-existing structures*** • ***Tabular data of reservoir pool and tail water elevations*** • ***Geo technical and geologic drawings*** • ***Construction historic data photos*** • ***GIS map*** • ***Instrumentation tabular data and plots*** *20. Boring logs sections with explanatory drilling apertures*	• ***Dam geometry*** *38. 3D model with pre-existing layer which enables to cut the cross section and super impose dam* *39. Water level and flows with piezometer readings per cross-section* *40. 3D Rose diagram showing the fracture pattern* *41. 3D model where can export cross sections or play views with layers turned on or off* *42. Ability to move between the rock testing reports and images and play views with layers turned on or off* • ***Simulations of different scenarios as consequence information*** • ***3D view of instrumentation and readings*** • ***3D visualization of side by side boring logs adjusted for elevation enables engineer to click and obtain the boring log report***
Hydrology and Hydraulics	• ***Site Plans for pre-existing structures*** *21. Breach parameters of the embankment* • ***Tabular data of reservoir pool and tail water elevations*** *22. Tabular data of reservoir inflow characteristics and volume-duration-frequency curves* *23. Hydrologic loading data for coincident pools for seismic PMF's and flood events* *24. Regional rainfall, inundation, PMF regional and HMR-51 maps*	• ***Dam geometry***
Structural	• ***Site Plans for pre-existing structures*** • ***Tabular data of reservoir pool and tail water elevations*** • ***Hydrologic loading data for coincident pools for seismic PMF's and flood events*** • ***Geo technical and geologic drawings***	• ***Dam geometry*** • ***3D view of instrumentation and readings***

Note:
1) Only the requirements which are repeating i.e. overlapping over two or more disciplines' requirements are marked in bold text
2) The first instance of occurrence of each requirement is numbered, and the repeating instances are listed in bullet format.