SANBA Tool: Knowledge Capitalisation and Lessons Learned on Dams and their Safety

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Summary

Much is known about dam design, construction and failure and degradation modes, though the information is scattered and sometimes lacks clarity. Consequently, it is interesting to develop tools that allow gathering, capitalizing and making explicit current and future information. These tools can be learning or documentation support systems. In this article, we present the prototype tool called SANBA, composed of a knowledge base, SANBA-dom, specifically developed for dam design, construction and failure and degradation modes (domain knowledge), coupled with a case base, SANBA-cas, which gives a detailed description of incidents and accidents that have occurred on structures (diagnoses, consequences and corrective actions). The method relies on 4 main stages: determining study granularity, field identification and structuring, implementing a computer tool and instantiation. Validations were carried out after the identification and instantiation stages. Two different technologies were used for the 2 components of the SANBA tool: the SANBA-cas component was implemented using Symfony (framework PHP open-source) and the SANBA-dom was implemented using a Wiki technology. Web technologies make formalized knowledge more accessible and simplify its capture. These bases are currently being filled and validated at Irstea Aix-en-Provence. Later, they will be accessible to external users for consulting and writing tasks as a function of the rights conferred to each type of user.

Introduction

Knowledge of dam design-construction and failure and degradation modes can be characterised by several elements:

- some of the knowledge is not explicit but tacit;
- much explicit knowledge exists but it is dispersed;
- knowledge exists in different formats such as texts, photographs and videos;
- this knowledge concerns the domain (description of design and construction, degradation phenomena, etc.), and feedback from experience from dams for which failures have occurred.

It is therefore useful to gather, capitalise and explain current and future knowledge [1]. The existence of such a tool has several advantages:

- to gather knowledge in a single tool and to enrich it progressively with the creation of new knowledge;
- to formalise feedback from experience on incidents and accidents that occur on dams;
- to create a training tool, for example, to help users find definitions, and train young experts;
- to produce a documentation tool: it permits users to refer to a dam having been subject to the same failure or accessing a recommendation for corrective action;
- to facilitate communication between users, notably through the definition of a common vocabulary. This communication tool can be used internally by a panel of experts dialoguing on the same problem and also externally between a non expert coordinator and a group of experts.

In this article, we present the prototype SANBA tool composed of a knowledge base, SANBA-dom, dedicated to dams and more specifically focused on their construction and their failure and degradation modes (knowledge of the domain) coupled with a case base, SANBA-cas, providing detailed descriptions of incidents and accidents that have occurred on structures (diagnostics, consequences and corrective actions). The first section is dedicated to a brief presentation of tools for capitalising knowledge and feedback from experience already developed in the domain of dams. The second section deals with the approach and methods implemented. The third section presents the results obtained.

Existing tools in the domain of dams

We distinguish tools that collect knowledge of a domain and tools that permit feedback from experience.

Bases dedicated to knowledge of the domain

As yet, no base has been built specifically to capitalise knowledge in the domain of dams. It should be noted that a dictionary is included in the base of the NPDP (National

Performance of Dams Program - npdp.stanford.edu/index.html). In particular, it defines in a few lines the different elements of dams and their pathologies and provides links to related terms. Furthermore, courseware on a DVD called VIGIE BARRAGE [2] has been developed for dam operators responsible for monitoring structures.

There are several civil engineering computer tools dedicated to formalising and capitalising knowledge on a domain, developed, for example, for motorway [4] and building [3] construction.

The site Wikirisk (http://wiki.cnri.fr/) is a collaborative encyclopaedia on industrial risks that forms a knowledge base, fueled by the CNRI network (Centre National des Risques Industriels). The objective of this project is to propose a collection of articles and definitions on risk, capable of constituting a reference framework for the community interested in industrial risks, which converges with our concerns.

Case bases of past accidents

Feedback from experience of dam failures was initially the subject of different publications of the ICOLD (International Commission on Large Dams) [5-7]. Computer tools have since been developed with, in particular, two open databases on the Internet (ARIA et NPDP) and a base on CD-ROM (BHDF). These three bases are considered in the following paragraphs.

ARIA base

The ARIA base is managed in France by the Ministry of Ecology, Sustainable Development, Transport and Housing (www.aria.developpement-durable.gouv.fr). It contains the incidents and accidents that have or would have had an effect on health and public safety, agriculture, nature and the environment.

On 23/04/2012, 40,000 accidents were recorded including 27 accidents involving hydraulic dams and linked to a failure of the structure (overflow, internal erosion, failure of gates, etc.). The period covered by the 27 cases is 1959-2011: 1 case in 1959, 1 case in 1963, 1 case in 2008, 17 cases in 2010 and 7 cases in 2011. Six of them occurred abroad.

Except for two of them formulated in a detailed file of thirteen pages, these cases are described quite briefly (190 words on average). Few associated documents are provided for all these cases: only 4 cases are illustrated by photographs. The fields structuring the detailed files of the ARIA base are presented in Table 1.

NPDP base

The NPDP base contains events that have occurred to American dams: they concern design, construction, inspection, modifications, incidents, etc. About 3,000 incidents are described in the NPDP up to 23/04/2012 described by texts of several hundred words. This database is accompanied by a dictionary that explains the technical terms of the domain.

Each incident is subject to one record in the base: it is possible to follow-up the different events on a dam through time. The fields structuring the detailed files of the NPDP base are presented in Table 1. It is noteworthy that many fields are often left blank (notably for photographs). Apart from the field giving the name of the dam, the field filled in systematically provides the description of the event.

BHDF base

The BHDF base (Bibliography of the History of Dam Failures) gathers data on dam failures collected by the Data Station for Dam Failures (DSDF-VIENNA) since 1980.

The fields structuring the detailed sheets of the BHDF base are presented in Table 1. The base contains the description of failures, the dimensions of the dams concerned and the causes of failure, the estimation of degradation when it is known and references from the literature. The database currently contains 323 failures of large dams, 445 failures of small dams and 133 failures of mine tailing dams. The data come from libraries, private databases, government and nongovernmental organisations, and universities [11]. It is important to underline that failures are not described by texts: the cause of failure is identified only by type, of which 14 are identified.

TABLE 1: COMPARISON OF FIELDS OF DIFFERENT BASES OF CASES OF PAST ACCIDENTS AND INCIDENTS

	ARIA	NPDP	BHDF	SANBA-cas
Characteristics of the structure	Installations concerned: - Site - Unit concerned - Prior geological studies * - Priming of the dam* * : only for one sheet	NPDP identifier Name of dam Type of structure Height Danger class Geographical status Nearest town Distance from the nearest town River Load Description of site, structure and materials	Name of dam Country Date of construction Type of dams Height Length Capacity	Identification (5 fields) Technical description (22 fields) Measurement system Hydrological data Available studies
Characteristics of accident or incident	Accident, its sequence, its effects and consequences Origin, causes, circumstances of the accident	Date of event Breach of structure (yes/no) Description of the failure Mode of failure Sub-type of event Description of event (a few hundred words at most)	Date of failure Causes of failure (14 types including unknown) Data on damage to persons Data on economic losses	Date Mode of damage
Actions performed following the accident or incident	Actions performed afterwards	Post-failure– actions performed after event Emergency action plan implemented Consequences		Corrective actions Behaviour after corrective actions
Lessons learned	Lessons learned	Lessons learned		
References and keywords	References	References and keywords	References	Sources used

Synthesis – Proposal of a new tool

The previous analysis showed that no tool is currently available that processes both knowledge of the domain and feedback from experience. Our project is to propose such a tool that we have called SANBA. It is composed of a knowledge base, SANBA-dom, dedicated to dams and based in particular on their design and construction and their modes of failure and degradation (knowledge of the domain) coupled with a case base, SANBA-cas, that contains detailed descriptions of incidents and accidents that have occurred on structures (diagnostics, consequences and corrective actions). Concerning knowledge of the domain, this tool carries on from the product VIGIE BARRAGE. The SANBA-dom tool goes further than the VIGIE BARRAGE tool in three main ways: (i) knowledge of the design and construction of structures, (ii) a greater number of potential users and with different levels of competences, and (iii) the possibility of consulting knowledge interactively via the Internet.

This knowledge base is susceptible to interest a wide section of the public including students, teachers, and debutant and experienced engineers in the domain working for different organisations such as government inspection services, engineering offices, regional authorities, entities managing and owning structures, research and education establishments.

The method used to develop the SANBA tool

The method we used to develop SANBA is based on several works, notably those of [8, 10]. It is structured in four main steps (cf. Figure 1) that are described in the following paragraphs.

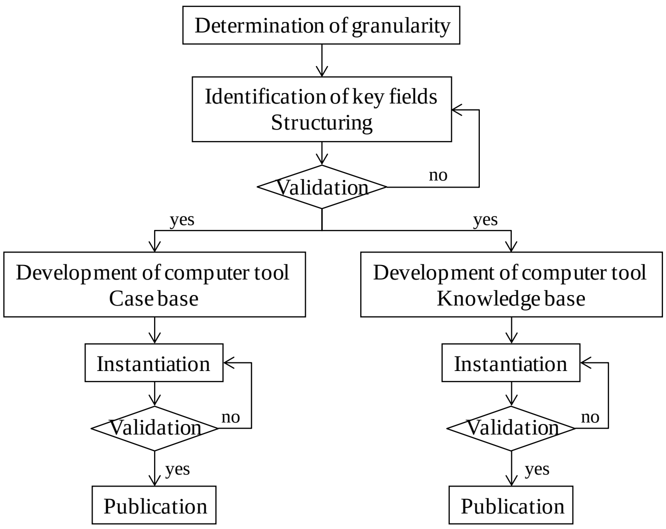

Figure 1: Method of building the SANBA tool

Determination of the granularity of the study

Granularity is formulated on the basis of questions to which the base must respond. Three levels of granularity can be considered:

- granularity of a lower level linked to the scale of the materials used in the structure of the component;
- granularity of a high level corresponding to the entire system: the dam, its foundation, the different ancillary works, etc.;
- granularity of intermediate level corresponding to a breakdown of the system into subsystems (drainage system, sealing system) then in different components (for the drainage subsystems: vertical drain, horizontal drain).

The objects of our study are ageing phenomena that affect the different subsystems and components of the dam. Thus we work mainly on granularity of intermediate and lower levels: for example, for the description of internal erosion through the embankment (intermediate level), it is specified that this mechanism depends on the transport of grains of embankment material (lower level).

Identification and structuring of the fields

The second step is aimed at identifying the fields structuring the base (“phenomena”, “indicators”, “corrective actions”, etc.) and the links between these fields (indicators “permit evaluating” a phenomenon, corrective actions “permit correcting” a phenomenon, etc.). This phase is followed by a validation step with experts. A new field identification and/or structuring phase is performed if necessary after the validation sessions.

Development of a computer tool

The tool has been built to conform to a certain number of constraints concerning:

- its structure: the fields of the base must be defined so as to inform the user pertinently and without ambiguity. The fields chosen must clearly describe the failure and degradation modes and the design and construction data and, reciprocally, the essential fields for describing failure and degradation modes and design and construction data must appear in the base. Likewise, the fields essential for pertinent feedback from experience must be well thought out (exhaustiveness);
- its validity: all the fields and their instances must be consensual, i.e. have received agreement from a group of experts;
- its pedagogic contribution: the multimedia character of the tool is interesting in terms of pedagogy;
- its user-friendliness: the design takes the user into account in order to make using the knowledge base user-friendly. Figures and photographs are used to this end;
- its open-endedness: it must be possible to integrate new knowledge easily in the base.

Two different computer technologies were used for each of the components of the SANBA tool: the SANBA-cas component is implemented on Symfony (framework PHP open-source) and the SANBA-dom component uses Wiki technology. Using Web technologies gives easy access to knowledge and simplifies its entry.

Instantiation

The instantiation step permits filling the different fields. It is carried out by authorised experts. The knowledge sources are multiple: scientific and technical literature, analysis reports, expert data, etc.

Results

The SANBA-dom knowledge base

SANBA-dom is an encyclopaedic tool based on design and construction and on dam failure and degradation modes. Figure 2 presents the fields describing the knowledge of the domain and its organisation.

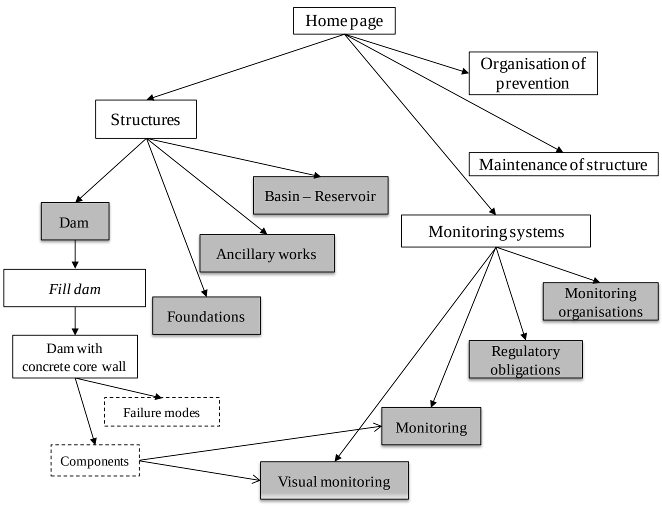

Figure 2. Partial view of the fields of the SANBA-dom tool

Although Wiki technology is used, we chose to build a structure of this base and fill each field with at least one instance. This tool can be used for teaching purposes: this structure makes it possible to introduce an initial learning process for apprentices.

The highest organisational level is “Structures”: this distinguishes embankment dams, gravity dams, arch dams and their foundations. Then for each type of structure are described:

- examples of structures characteristic of this type of dam: for example, the dam of Serre-Ponçon for a rockfill dam with a central impervious core;
- they are characterised by failure and degradation modes. For example, for gravity dams the following are described: shearing in the body of the dam, shearing at the interface of the body of the dam and the foundation;
- the components of these structures: on the one hand, the function provided by the dam component itself (upstream and downstream fill, drainage system, sealing system, etc.) and information on their design and construction and, on the other hand, the measurement devices equipping the structure;
- the main characteristics of these structures. The dimensions of a dam are presented here (height, width of crest, batter slopes, etc.), the important dates (construction, priming, etc.) and the legislation governing their inspection.

The tree structure of the fields of the lower level is described in Figure 2. It is noteworthy that certain pages are common to several instances, thus the page describing drainage systems (Component Header) is common to all the structures (embankment, gravity and arch). Therefore there is no duplication of Figure 2 for each of the Types of structure.

The different fields can be instantiated by data of different formats: texts, photographs, videos.

Figure **3** provides an example of a page of the SANBA-dom tool. The pages are in French at present, but an English translation is planned. The page presented describes the internal erosion mechanism (“Mécanisme d’érosion interne” in Figure **3**) and describes the different tearing phenomena (“Phénomènes d’arrachement” in Figure **3**) and Transport phenomena (“Phénomènes de transport ” in Figure **3**).

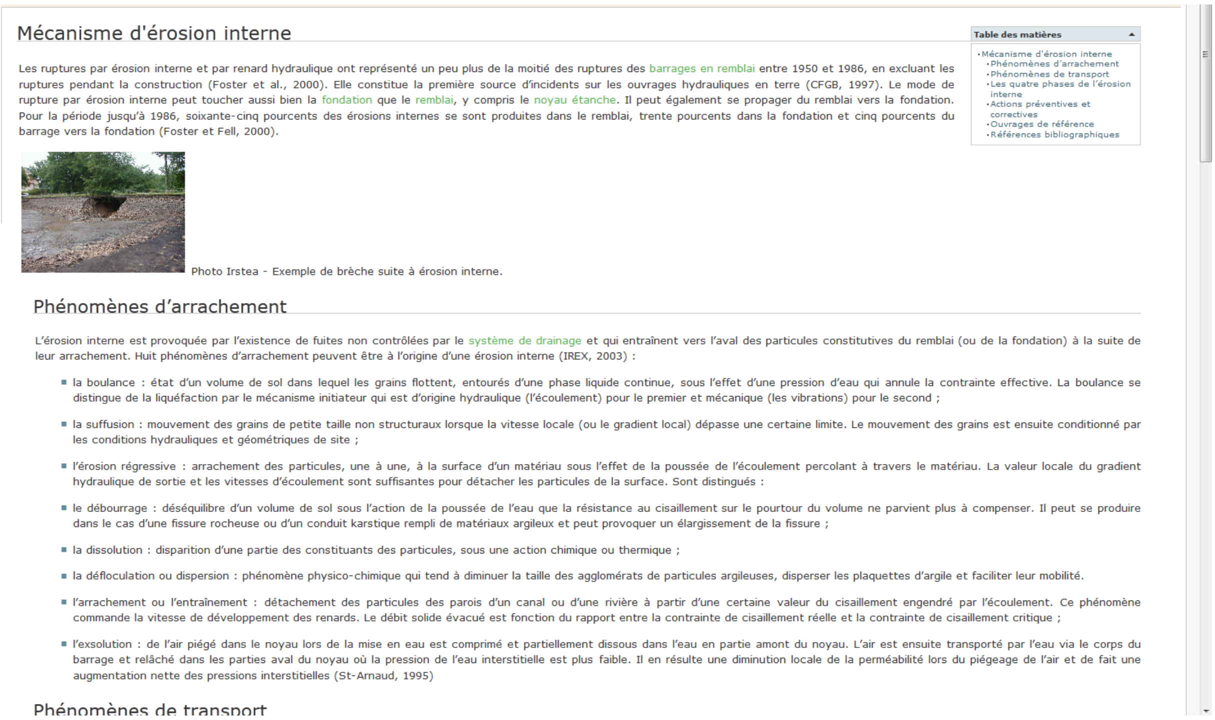
Mécanisme d'érosion interne

Table des matières
- Mécanisme d'érosion interne
  - Phénomènes d'arrachement
  - Phénomènes de transport
  - Les quatre phases de l'érosion interne
  - Actions préventives et correctives
  - Ouvrages de référence
  - Références bibliographiques

Les ruptures par érosion interne et par renard hydraulique ont représenté un peu plus de la moitié des ruptures des barrages en remblai entre 1950 et 1986, en excluant les ruptures pendant la construction (Foster et al., 2000). Elle constitue la première source d'incidents sur les ouvrages hydrauliques en terre (CFGB, 1997). Le mode de rupture par érosion interne peut toucher aussi bien la fondation que le remblai, y compris le noyau étanche. Il peut également se propager du remblai vers la fondation. Pour la période jusqu'à 1986, soixante-cinq pourcents des érosions internes se sont produites dans le remblai, trente pourcents dans la fondation et cinq pourcents du barrage vers la fondation (Foster et Fell, 2000).

Photo Irstea - Exemple de brèche suite à érosion interne.

Phénomènes d'arrachement

L'érosion interne est provoquée par l'existence de fuites non contrôlées par le système de drainage et qui entraînent vers l'aval des particules constitutives du remblai (ou de la fondation) à la suite de leur arrachement. Huit phénomènes d'arrachement peuvent être à l'origine d'une érosion interne (IREX, 2003) :

- la boulance : état d'un volume de sol dans lequel les grains flottent, entourés d'une phase liquide continue, sous l'effet d'une pression d'eau qui annule la contrainte effective. La boulance se distingue de la liquéfaction par le mécanisme initiateur qui est d'origine hydraulique (l'écoulement) pour le premier et mécanique (les vibrations) pour le second ;
- la suffusion : mouvement des grains de petite taille non structuraux lorsque la vitesse locale (ou le gradient local) dépasse une certaine limite. Le mouvement des grains est ensuite conditionné par les conditions hydrauliques et géométriques de site ;
- l'érosion régressive : arrachement des particules, une à une, à la surface d'un matériau sous l'effet de la poussée de l'écoulement percolant à travers le matériau. La valeur locale du gradient hydraulique de sortie et les vitesses d'écoulement sont suffisantes pour détacher les particules de la surface. Sont distingués :
- le débourrage : déséquilibre d'un volume de sol sous l'action de la poussée de l'eau que la résistance au cisaillement sur le pourtour du volume ne parvient plus à compenser. Il peut se produire dans le cas d'une fissure rocheuse ou d'un conduit karstique rempli de matériaux argileux et peut provoquer un élargissement de la fissure ;
- la dissolution : disparition d'une partie des constituants des particules, sous une action chimique ou thermique ;
- la défloculation ou dispersion : phénomène physico-chimique qui tend à diminuer la taille des agglomérats de particules argileuses, disperser les plaquettes d'argile et faciliter leur mobilité.
- l'arrachement ou l'entraînement : détachement des particules des parois d'un canal ou d'une rivière à partir d'une certaine valeur du cisaillement engendré par l'écoulement. Ce phénomène commande la vitesse de développement des renards. Le débit solide évacué est fonction du rapport entre la contrainte de cisaillement réelle et la contrainte de cisaillement critique ;
- l'exsolution : de l'air piégé dans le noyau lors de la mise en eau est comprimé et partiellement dissous dans l'eau en partie amont du noyau. L'air est ensuite transporté par l'eau via le corps du barrage et relâché dans les parties aval du noyau où la pression de l'eau interstitielle est plus faible. Il en résulte une diminution locale de la perméabilité lors du piégeage de l'air et de fait une augmentation nette des pressions interstitielles (St-Arnaud, 1995)

Phénomènes de transport

Figure 3. Example of a page of the SANBA-dom base (in French)

Base of past cases of accidents and incidents: SANBA-cas

The input page of the SANBA-cas base presents the list of dams classed by type of structure: embankment dam, rockfill dam, gravity dam, buttress dam, arch dam, multiple arch dam, arch-gravity dam, other, unknown. Clicking on a specific dam opens a second window that describes the dam according to the 5 categories of field presented in Table 1: structure characteristics, accident or incident characteristics, follow-up, lessons learned and references.

As can be seen in Table 1, the fields are more or less detailed as a function of the tool considered. Regarding the SANBA-cas tool, we have chosen to:

- Provide an exhaustive description of the dam: 22 fields (dimensions, type of foundation sealing system, type of drainage, etc.) can be filled;
- List all the monitoring systems and their types: for example, the dam is equipped with 3 pressure cells for the measurement of piezometry. We felt it was important to present these measurement devices which play an essential role in monitoring dam behaviour. These devices are not listed in the 3 other tools;
- Not indicate the specific "lessons learned" fields but indicate the lessons learned in a comments field. It is not always possible to learn a specific lesson from an accident: it could be linked to a cause already known, such as inappropriate design or construction, poorly adapted or insufficient maintenance, etc.

We have sought to facilitate the writer's task, notably by building two structures. First, pull-down lists are proposed to fill-in most of the fields (excluding the comments): this permits using the same terms from one structure to another. Second, the comments fields can be filled in numerous fields: they allow providing interesting additional information.

In the same way we have sought to facilitate the reader's task: only the fields filled in are displayed on the screen; the first page provides a global view and the zones "See" allow the reader to obtain more details (cf. Figure **4**). The reader is free to learn more about the structure consulted if he/she wishes.

Figure 4 gives an example of a description Cublize dam which had been subject to internal erosion and the onset of sliding in the dam core in 1988. The previous page displays the description of the incident and some of the corrective actions undertaken following it. By clicking on "See" the user can obtain more details on the corrective actions. A diagram presenting the cross-section of the dam is also available. The pages are currently in French but an English translation is planned. The page presented describes Cublize dam that had been subject to an internal erosion mechanism in the fill ("(« Erosion interne dans le remblai" shown in Figure **4**) and describes the phenomenon ("Typologie" in Figure **4**), with the phenomena occurring on the dam

("Description" in Figure **4**) and the corrective actions ("Actions correctives" in Figure **4**).

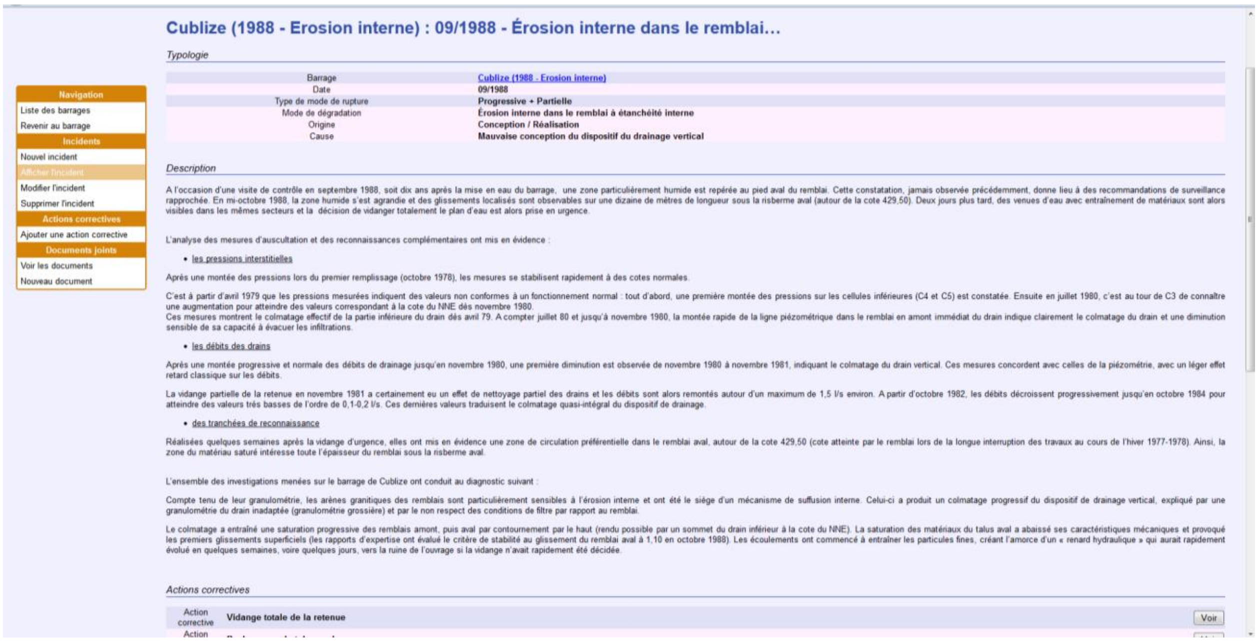

Figure 4. Example of a page of the SANBA-cas base (in French)

Access rights

Access rights were considered in-depth for each of the components of the SANBA tool.

The tool can be accessed by the general public regarding the SANBA-dom component once the published data have been validated (cf. Figure 1). Regarding the SANBA-cas component, two modalities can be distinguished. Certain sheets will be accessible to the public: these are cases of known incidents already analysed in publications. These sheets can be subject to referrals from and to the SANBA-dom base. Others will not be accessible to the general public but only to experts with specific rights: these are confidential cases that have not been published.

Conclusion

In this article, we proposed an approach to developing a tool for capitalising knowledge and feedback dedicated to dams and their safety. The SANBA prototype tool is composed of a knowledge base, SANBA-dom, dedicated to dams and more particularly to their design and construction and to their failure and degradation modes (knowledge of domain) coupled with a case base, SANBA-cas, that provides a detailed description of incidents and accidents that occurred in structures (diagnostics, consequences and correctives actions). The computer technologies implemented are adapted to the objective of each of the components. Using web technologies facilitates access to knowledge and simplifies its acquisition. These two tools should soon be linked by several fields. For example, in SANBA-dom the chapter describing internal erosion in dam fill material, a phenomenon that can lead to the destruction of the dam, refers the user to examples of dams present in SANBA-cas that have been subject to the same pathology and vice-versa.

These bases are currently being filled and validated at Irstea Aix-en-Provence, after which they will be accessible to an external audience for consultation and enrichment according to the access rights conferred to each type of user. The problem of experts unwilling to disclose their knowledge could slow down acquisition for the base. This problem has been dealt with by several authors including Lightfoot [9] who classed unwilling experts into two categories: experts who supply intentionally deformed knowledge, and recalcitrant experts. The pages of the SANBA tool will be written by selected and willing authors: this should reduce problems linked to experts unwilling to disclose their knowledge. Furthermore, a proofreading procedure is planned before diffusion: it will help to enhance the quality of the knowledge available in the tool.

The SANBA-dom base can be used for training purposes. We wanted a strong structure for the base from the outset, and it should help users to understand the different major elements of a dam, its operation and the context: components, failure modes, legislation, etc. We think that two perspectives appear interesting regarding teaching:

- on the one hand, the description of pedagogical programmes of varying lengths that focus on a given theme, for example, understanding a specific mechanism like internal erosion. This entails providing a sequential course divided into modules: for internal erosion the modules could concern the components affected, the causes of the phenomenon, its detection, the recommended corrective actions, the presentation of cases of dams that have been subject to this mechanism, etc. This course could be sequenced: it would be vital, for example, for a case study of the internal erosion mechanism, to know the components involved, in order to build a prerequisite module before going on to studying the causes of the phenomenon;
- on the other hand, the development of specific pages proposing exercises (calculations, QCM, solutions of cases). These pages could be the basis of a specific module in the teaching programme.

The approach and structure of the tool can be used for other civil engineering structures and other domains.

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