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The new ICOLD Bulletin on impervious geomembranes for dams

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ABSTRACT: Geomembranes have been used as waterproofing element in dams since 1959. At present their application includes rehabilitation of all types of dams, and new construction of RCC and fill dams. ICOLD, the International Commission on Large Dams, has dedicated two theme bulletins to the use of geomembranes in dams, one in 1981 (Bulletin 38) and one in 1991 (Bulletin 78). A new bulletin has been prepared by an ad-hoc European Working Group, under the aegis of the ICOLD Committee on Materials for Fill Dams. The new bulletin, composed of 9 chapters and 3 appendixes, describes the classification and characteristics of geomembranes, discusses the criteria and recommendations for design, construction and operation, and details the application of geomembranes to construction and repair of fill dams, to repair of concrete and masonry dams, to construction of new RCC dams, and to repair of joints and cracks. Underwater repair, Quality Control, and guidance to technical contents of contracts are also addressed. The paper illustrates the contents of the bulletin, discusses the main issues of the present state-of-the-art, and provides some statistics as emerged from the database.

1 INTRODUCTION

Application of impervious geomembranes on large dams started at the end of the 1950s, in construction of new fill dams (1959 Contrada Sabetta, Italy, 1960 Dobsina, Slovakia, 1960 Terzaghi, Canada). Being intrinsically pervious, fill dams need a separate component to provide watertightness. The concept of using synthetic impervious materials instead than conventional materials such as clay, concrete or asphalt concrete, certainly derived, among other considerations, from the good performance of embedded Polyvinyl Chloride (PVC) waterstops on the huge number of concrete dams worldwide that rely on their use to stop water infiltration at joints. A geomembrane system on the upstream face of a dam can be considered, from a conceptual point of view, as one wide waterstop sealed at the abutments and bottom.

Starting from 1971, the use of geomembranes was extended also to rehabilitation. In 1981, the International Commission on Large Dams (ICOLD) published a first theme publication on geomembranes, Bulletin 38, “Use of thin membranes in fill dams”. Geomembranes were defined as “thin product with a thickness from one to a few millimetres, constituted of a flexible watertight material ... [that] ... may be prefabricated at works and then transported to the site, or prepared and positioned directly on the site (in situ).” The use of a cover layer was considered mandatory, the height of 30 m, and a surface of modest dimensions, a reasonable limit for an upstream geomembrane facing. Increasing the limit height to 40 m was based on foreseen future improvements in technique and materials.

The use of geomembranes gradually extended to restore impermeability in all types of dams: concrete gravity dams, buttress dams, arch dams, multiple arch dams, earthfill dams, rockfill dams with concrete facing (CFRD), and rockfill dams with asphalt facing. In the early 1980ies, just a few years after the first Roller Compacted Concrete (RCC) dam was built, geomembranes were used to provide impermeability to new RCC dams. In 1991, ICOLD published Bulletin 78 “Watertight geomembranes for dams – State of the art”. Geomembranes were referred to as materials mainly prefabricated, and in-situ membranes as products of less and less frequent application. The use of geomembranes was considered an established technique for new construction and rehabilitation of fill dams, as an emerging application for rehabilitation of concrete and masonry dams, and as “Future prospects” in application to new RCC dams. Concerning limit height, “There is no reason to recommend a specific height limitation on the use of geomembranes in embankment dams".

The early 1990ies saw an increasing application of geomembranes to large dams. Europe was the main developer and user of geomembranes systems on dams, and the need for an updating on current practice and trends was more deeply felt in European countries. A European Working Group for geomembranes and geosynthetics as facing materials for das was established in 1993. The group was formed by dam designers and owners, by geomembrane specialists and scientists, by specialist contractors. The group investigated more than 80 dams in Europe, establishing a database, as further described in the following chapter.

In 1999, based on the findings of the database, on the increasing use of geomembranes, and on the developments in design and installation techniques, ICOLD Committee on Materials for Fill Dams, who had published Bulletins 38 and 78, gave the group an official mandate to prepare a new bulletin on geomembranes, to address design, manufacturing, installation, Quality Control and contractual aspects. The group was extended to include worldwide leading experts in the field of geomembranes.

2 BASIS OF NEW BULLETIN

The new bulletin has been based on the personal knowledge and experience of the members of the group, on the data contained in the database that has been extended to include dams all over the world, and on additional information available in international literature.

The preparation of the database has been carried out by means of a Technical Form, circulated among owners of dams. The Technical Form is a 6-page document consisting of one section for main information (characteristics and service conditions of the dam, type of geomembrane and characteristics of geomembrane system, owner's comments on efficiency, durability, technical and economical effectiveness of the system), and of one section with additional information on the geomembrane system, on its installation, on quality control, and on costs. Incomplete forms were implemented with data from available relevant literature (ICOLD international congresses and Executive Meetings, conferences of ICOLD National Committees, articles in specialised magazines), and with contributions of designers involved in the project.

3 THE NEW BULLETIN

The new bulletin consists of 9 chapters and 3 appendixes. The first 3 chapters are general chapters, related to issues that are common to all types of dams. Chapters 4, 5, 6 and 7 are dedicated respectively to fill dams, to concrete and masonry dams, to RCC dams, and to special applications. Chapters 8 and 9 address Quality Control and contractual aspects.

3.1 *Chapters 1, 2 and 3*

Chapter 1 is a general introduction to geosynthetics, addressing their classification in several distinct families according to their function, and outlining their fields of application. Chapter 2 describes the classification and characteristics of the various types of geomembranes, and discusses materials configuration, seaming, testing, and behaviour in service. The geomembranes considered are factory-made polymeric and bituminous geomembranes. In situ impregnated geotextiles and sprayed liners based on polyurethane and polypropylene resins, which are closer to the family of the resins and less and less frequently used, are not subject of the bulletin, but have been included in the database. Table 1 lists all types of geomembranes used in dams.

Table 1. Geomembranes in dams.

Type	Tot. exp.	Tot. cov.	Tot.	Oldest exposed	Oldest covered
PVC	73	70	143	1974	1960
LLDPE	0	28	28	–	1970
HDPE	2	11	13	Not kn.	1978
IIR, EPDM	5	4	9	1982	1959
CSPE	3	5	8	Not kn.	1981
PP	1	2	3	Not kn.	Not kn.
CPE	0	3	3	–	1970
Ox. Bit.	7	10	17	1973	1978
SBS	0	1	1	–	1996

Tot. exp.: Total exposed
Tot. cov.: Total covered
Tot.: Total
PVC: PolyVinyl Chloride
LLDPE: Linear Low Density Polyethylene
HDPE: High Density Polyethylene
Not kn.: Not known
IIR: Polyisobutylene
EPDM: Ethylene-propylene diene monomer
CSPE: Chlorosulphonated polyethylene
PP: Polypropylene
CPE: Chlorinated polyethylene
Ox. Bit.: Oxidised bitumen
SBS: Styrene-butadiene-Styrene

Chapter 3 discusses the loads and stresses that are exerted on geomembranes in dam applications. The loads and stresses relevant to a particular type of dam are addressed in the relevant dedicated chapters.

While polymeric geomembranes have been applied to all type of dams, bituminous geomembranes have been installed only on the gentler slopes of embankment dams, and mainly in France.

3.2 *Chapters 4, 5, 6 and 7*

In chapters 4, 5, 6 and 7, significant examples are illustrated by typical cross sections and details.

3.2.1 *Fill dams*

In fill dams, geomembranes have been used in 60% of cases in new construction, in 40% as rehabilitation measure of asphalt concrete facings and concrete facings (CFRDs).

Chapter 4 analyses the loading conditions and available configurations in fill dams: upstream exposed geomembrane upstream covered geomembrane, and central geomembrane. Approximately in 90% of dams, the geomembrane is in upstream position, which is preferred to minimise uplifts and uncontrolled water presence in the dam body, improving stability and safety. In about 10% of the total, and mainly in China, the geomembrane has been used as central core. Pros and cons of upstream exposed/covered and central solutions are discussed.

Table 2. Geomembranes in fill dams.

Geomem-brane is	PVC	LLDPE	Bit.	HDPE	Elast.	CSPE	PP	CPE
Exposed	21	1	7	2	5	2	1	0
Covered	54	25	11	10	4	4	2	2
Unknown*	5	–	–	1	2	1	1	–
Total	80	26	18	13	11	8	4	2

GM: Geomembrane
Bit.: Bituminous
Elast.: Elastomeric & EPDM
*: Unknown if exposed or covered

Design aspects such as the characteristics and stability of the various layers, the anchorage at boundaries, the anchorage over the dam face, and installation techniques, are analysed. Specific aspects for rehabilitation are the anchorage systems, designed depending on the type and strength of the existing facing (asphalt concrete or concrete).

Figure 1. Bovilla fill dam, Albania 1996: PVC geomembrane.

3.2.2 *Concrete and masonry dams*

In concrete and masonry dams, geomembranes have been generally used for rehabilitation. In new construction, their use concerns partial application at heel. Rehabilitation is generally made on the entire upstream face. Partial repair sealing systems have been used to seal specific joints at heel or cut off wall (Kölnbrein 200 m high arch dam and Schlegeis 131 m high arch dam, both in Austria), or joints with failed joint sealant (Vale do Rossim, Portugal).

PVC geomembranes are used in 37 cases on a total of 43 dams.

Table 3. Geomembranes in concrete and masonry dams.

Geomembrane is	PVC	LLDPE	CSPE	CPE	Total
Exposed	36	0	1	1	38
Covered	1	2	1	1	5
Total	37	2	2	2	43

Out of 43 concrete dams around the world that have used geomembranes for rehabilitation, 32 have been waterproofed with the same exposed drained system that has been described in Bulletin 78, and which is patented. Performance history of this exposed system is now approaching 30 years, and field results have proven its capability of extracting and discharging water already permeating the concrete, for example at Pracana dam, where the exposed PVC geomembrane has helped slowing the alkali-aggregate reaction (Liberal et al. 2003). Among the various design and installation aspects addressed, the possibility of reducing uplift with a drained system, and recent developments allowing underwater repair of the entire upstream face.

Figure 2. Pracana dam, Portugal 1992: PVC geomembrane.

3.2.3 *RCC dams*

In RCC dams geomembranes have been used since 1984 in new construction, and since 2000 in rehabilitation. Geomembranes have been used to provide impermeability to the upstream face (24 dams), or as an external waterstop placed on the contraction joints or on new cracks (5 applications, of which 2 on the same dam, where the waterstop was placed at construction to waterproof the joints, and after first impoundment to waterproof a crack).

Basically all dams have been waterproofed with one of two available solutions: exposed geomembrane or covered geomembrane. Both solutions are patented.

The exposed system, an evolution of the exposed geomembrane system conceived for repair of dams, was first adopted in 1990 (Riou RCC dam, France). Outstanding projects completed with this system are the highest RCC dam in the world (Miel 1, Colombia, 188 m, 2002), and the highest RCC dam in USA (Olivenhain, 97 m high, 2003). The covered system was first installed in 1984. Outstanding projects are Cindere RCC dam, Turkey, 107 m, and Capanda RCC dam, Angola, 110 m.

Table 4. Geomembranes in RCC dams.

Geomembrane is	PVC	LLDPE	HDPE	Total
Exposed on face	10	0	0	10
Covered on face	15	1	1	17
Exposed on joints	3	0	0	3
Exposed on cracks	2	0	0	2*
Total exposed	15	0	0	15
Total covered	15	1	1	17
Total dams	30	1	1	32

* One installation made on same dam where geomembrane had already been installed on joints

Figure 3. Olivenhain RCC dam, USA 2003: PVC geomembrane.

3.2.4 *Special applications*

Special applications are basically related to an CARPI external patented waterstops system that can be installed since construction (on contraction joints of RCC dams), or be used to rehabilitate cracks in concrete facings (CFRDs, concrete dams, and RCC dams).

The external waterstop system consists of a support layer, impeding that the waterproofing liner intrudes in the active joint/crack at maximum opening under the maximum water head, and of the waterproofing liner, a PVC geocomposite watertight anchored along the perimeter with a mechanical seal. Examples on concrete facings are Strawberry CFRD (50 m high, USA, failing joints) and Vale do Rossim gravity dam (27 m high, Portugal, 1996, failing joints). Examples on RCC dams are Dona Francisca (63 m high, Brazil, 2000, failing joints and cracks before first impoundment), Platanovryssi (95 m high, Greece, in 1998 on contraction joints during construction, and in 2002 on a crack formed at first impoundment).

3.3 *Chapters 8 and 9: Quality Control and contractual aspects*

Quality Control and Quality Assurance are addressed for all the steps concurring to construct a reliable waterproofing system, i. e. manufacturing, transport, and installation. The chapter includes type and frequency of controls, testing procedures, acceptance criteria.

The chapter on contractual aspects provides some guidelines on how procurement of geomembrane systems for dams shall be done, including a checklist of the data for design.

To assure that the outcome of the waterproofing project is in line with the expectations and respectful of the criteria of safety, durability, capital investment and cost of maintenance, previous experience of the material in similar application, and previous experience of the designer and installer, are recommended. A table with suggested minimum requirements is included.

3.4 *Appendixes*

The appendixes consist of the database, of a list of geomembrane technology terms and definitions, and of leading international references.

4 CONCLUSIONS

Geomembrane systems have reached a high degree of sophistication and reliability. If adequately designed and installed are considered a long lasting waterproofing method. The satisfaction on the technical and economical efficiency of the installed systems, as expressed by the owners, is very high.

The height of lined dams has dramatically increased over the years. There is now no theoretical limit: geomembranes records on new fill dams is 196 m (Karahnjukar, Iceland 2005), on old gravity dams 174 m (Alpe Gera, Italy 1993/1994), on new RCC dams 188 m (Miel 1, Colombia 2002).

Performance after decades of service shows that the very low permeability of geomembranes is maintained over time, and that geomembranes left exposed on the upstream face are able to resist very aggressive environments (UV rays, ice, waves, impact of debris, etc).

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