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学位授与の要件	自然科学研究科地球・環境システム科学専攻 （学位規則第４条第１項該当）
学位論文の題目	Research on Underground Dams – Design and Construction Concepts （地下ダムの設計と施工に関する研究）
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学位論文内容の要旨

Surface water sources have been the first choice of water supply for drinking, agriculture and industries in most parts of the world since time immemorial and for increasing population and modern life. However, the surface water sources are usually prone to pollution, resulting in diseases when used without treatment. Furthermore, the high cost involved, the unavailability of land for the storage of impounded surface water, effect on biological life and environmental concerns and the social dislocations that surface water developments cause make the construction of surface dams controversial and costly for many governments. There is therefore much pressure on available water resources in many parts of the world. For remote, isolated and sparsely populated settlements, groundwater supply from hand dug wells and boreholes are depended on as the most feasible and economical option. However, groundwater levels and yields could be variable, following intensive use and seasonal rainfall patterns.

To increase water supply from groundwater resources, various technologies have been developed in many parts of the world and underground dam is one of such technologies. It has received much attention in Japan, Brazil and India since the 1970s and many of the dams have been constructed in these and other countries. At present, there is a renewed interest in it as a feasible option for augmenting groundwater supplies, especially in sub-Sahara Africa where increasing human population, industrialization and changing lifestyles require abundant water supplies but which are not readily available. The development of underground dams is, however, limited by the lack of information on its design and construction of the dams. Many underground dams have been constructed and managed in some countries but the engineering design and construction are more of an art; based on the experience and practice of the particular construction company. Cases have been reported where the desired underground storage was never achieved because of poor design and construction and which thus led to the leakage of the stored groundwater.

The purpose of the thesis, therefore, was to collect and collate information and data on underground dams of the world, to test some design and construction concepts, and to propose methods for improving on the design and construction of underground dams. To achieve the above-mentioned objectives, both desk-top and laboratory activities were carried out. The presented work is in basic theoretical but the scope has also been to acknowledge some practical aspects of effective porosity and grouting for underground dam construction.

The concepts of underground dam, effective porosity and grouting were reviewed. The basic concept, types, the advantages and disadvantages, the requisite site conditions, and the utilization of underground dam as water supply systems in Japan, India, South Korea, Burkina Faso, Tanzania, Brazil, Europe and the Americas; and previous research works on underground dams are presented. This is followed with a review of effective porosity, as an important concept in saturated-unsaturated fluid flow and in determining the storage capacity of underground dams, among others. Then, a review of grouting of underground structures was carried out. From the review, it was found that major construction problems are related to water loss by seepage through the dam wall which is likely to be caused by stored groundwater seeping through the bedrock because the bedrock is very permeable to water, the dam wall not extending well enough into the relatively impermeable layer below and poor construction of the cutoff walls; thus leaving gaps between the mixed soil-cement columns or grouted columns forming the walls.

Effective porosity is an important concept in determining the radius of action of grouts. However, methods for it determination are not evident. Therefore, methods for determining the effective porosity of porous media under saturated-unsaturated conditions are proposed and the results of one dimensional horizontal laboratory injection tests on the validity of the proposed method are presented. Furthermore, the radius of action of chemical grouts and the use of such grouts for the construction of the cut-off wall of underground dams was investigated. The validity of the mathematical relationships involved was tested in the laboratory and the results also presented.

The general conclusions of the thesis and recommendations for future research on the design, construction and utilization of underground dams; the concept of effective porosity, degree of saturation and chemical grouting are presented.

論文審査結果の要旨

本研究は，地盤内の間隙の中に地下水を貯留する手法である地下ダムに関する研究である。研究の目的は，地下ダムの設計と施工に関して探究することとである。すなわち，多孔質の地盤内に地下ダムのような止水壁を施工する方法として，地盤内に薬液注入する際の設計で必要な有効間隙率の求め方と対象流域の貯留帯水層の底部の難透水層の連続性の計測方法についての基礎的な研究を行った。

最初に世界における地下ダムに関する実施例をレビューし，止水のためと，間隙中への水の保留に関係する有効間隙率と地中の止水壁の施工技術を総整理して，その施工上の問題点を抽出した。その結果，多くの地下ダムの鉛直の止水壁の施工を行う際に，その注入孔のピッチの設計，施工がきわめて経験的に実施されていることを指摘した。

したがって，その設計に最も大切な有効間隙率の原位置での計測方法の理論的な解析方法とその試験方法を提案した。また，その提案した試験法の妥当性を検証するために，室内における一次元の注入試験と軸対称のモデル実験を実施した。これらの実験結果より，本研究で提案する試験方法は，従来計測が不可能とされていた薬液注入での有効間隙率がきわめて簡単な定流量注入試験によって求められることがわかった。

また，広範囲の流域の地中の帯水層中に地下水を貯留する際に問題となる貯留層の底部の連続性に関しては，従来は，ボーリングデータから予測していたが，これに関しても，比抵抗トモグラフィーと GPS を結合させて広範囲の難透水層の連続性の調査法を提案している。

これらの本研究の成果は，従来，経験的に設定して設計していた有効間隙率の値を定量的に原位置で評価できる手法であり，地下ダム建設の際の止水壁の設計・施工と利用可能な地下水の予測に対しての信頼性と経済性を向上させた，きわめて貴重な研究であり，学位（学術）を授与するに値する研究と評価した。