The Drinking Water, Sewerage, and Treatment Manual (MAPAS) As a New Support Tool for the Design of Urban Hydraulic Structures

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Abstract: Water industry companies need infrastructure capable of satisfying the hydraulic requirements for which they were designed. Moreover, in order to fulfill that objective, they should meet the structural requirements that assure an adequate lifespan and the capacity to withstand daily mechanical actions as well as the occurrence of earthquakes and/or gusts of wind. In Mexico there are local construction regulations that dictate the considerations that should be taken into account for a structural design, as well as diverse manuals that aid in this purpose, nonetheless, they commonly focus on the construction of conventional urban infrastructure. In the case of urban hydraulic works such as elevated tanks and treatment plants, which must be considered as priority structures of public interest, there isn't enough public information for their design and construction. For that reason, as part of the recent update of the Drinking Water, Sewerage, and Treatment Manual (MAPAS) the "Structural Design" book aids with the structural design of urban hydraulic works so as to standardize criteria for the design of buried, elevated and surface deposits, as well as support structures. Design and construction recommendations for these structures were also included based on the experience of the operators in charge of the distribution networks for drinking water, sewerage and water treatment. In the present article, the content and objectives of the book are broken down in a simplified form as well as their potential applications and usage. Interdisciplinary work in the design and construction of urban hydraulic infrastructure is also encouraged here.

Keywords: design; tanks; drinking water; manual.

1. Introduction

One of the great water challenges that we face at a global level is giving adequate drinking water, sewerage, and water treatment to the population, due, primarily, to the accelerated demographic growth and water scarcity. Having these resources is a determining factor in the quality of life and integral development of human beings. In Mexico diverse actions are taken to deal with water needs. A fundamental part of this strategy is the strengthening of operating-organizations and providers of drinking water, sewerage and treatment.

In this sense, the National Water Commission (Conagua) in conjunction with the Mexican Water Technology Institute (IMTA), carried out the update of the Drinking Water, Sewerage, and Treatment Manual (MAPAS) which is comprised of 55 specialized, technical books in Spanish that contain the most recent technological advances in the design, construction, operation, and maintenance of urban hydraulic works so as to develop more efficient, safe and sustainable infrastructure as well as better-trained human resources.

MAPAS was developed as a support tool to guide the daily tasks of technicians, specialists and water industry workers in general, giving them criteria for adequate management, reducing their operating costs and promoting the use of recently-developed technologies as well as sustainable energy in processes when applicable. Additionally, it has the general goal of achieving better use of the country's surface and underground water with consideration for the needs of new infrastructure as well as the care and maintenance of the existing one.

2. The Drinking Water, Sewerage, and Treatment Manual

The Drinking Water, Sewerage, and Treatment Manual (MAPAS) was created as an instrument for the reference, consultation, and dissemination of all the criteria, policies, guidelines, instructions, arrangements,

procedures, concepts, standards, rates, and parameters that the National Water Commission, in its role as a legal entity, considered important to update, standardize, or establish. The purpose of this is maintaining the lowest common denominator of quality in the services and attention that the Subsector of Drinking Water and Sewerage delivers through the National Water Commission as well as the state and municipal enterprises that deliver these services to Mexico.

The MAPAS was created in 1992 and has since undergone several modifications and updates, the last of which was in 2007, for that reason in 2013, updating efforts on behalf of the Conagua and the Mexican Water Technology Institute (IMTA) began which concluded with the publication of the new version of the Manual in 2015. Nonetheless, the updating process wasn't easy, it required the consultation and participation of many experts on the matter, allowing for the expression and reflection upon the experience of the different topics which each book covers, allowing, on occasion, for differences of opinions which arise due to the nature of the topics.

Given the information that was collected and the opinions afforded by diverse actors, the classification of the topics presented follows the integration, operation and maintenance process of an operating organization as well as the networks of drinking water, sewerage, and treatment systems that operates by virtue of the manual having broad and specialized information which considers among other things, standards, procedures, criteria, parameters, policies, terms, and statutes in different topics related to the subsector of drinking water, sewerage, and water treatment. The structure of the five modules was taken as a base to aid the classification and consultation of different books (*see Figure 1*).

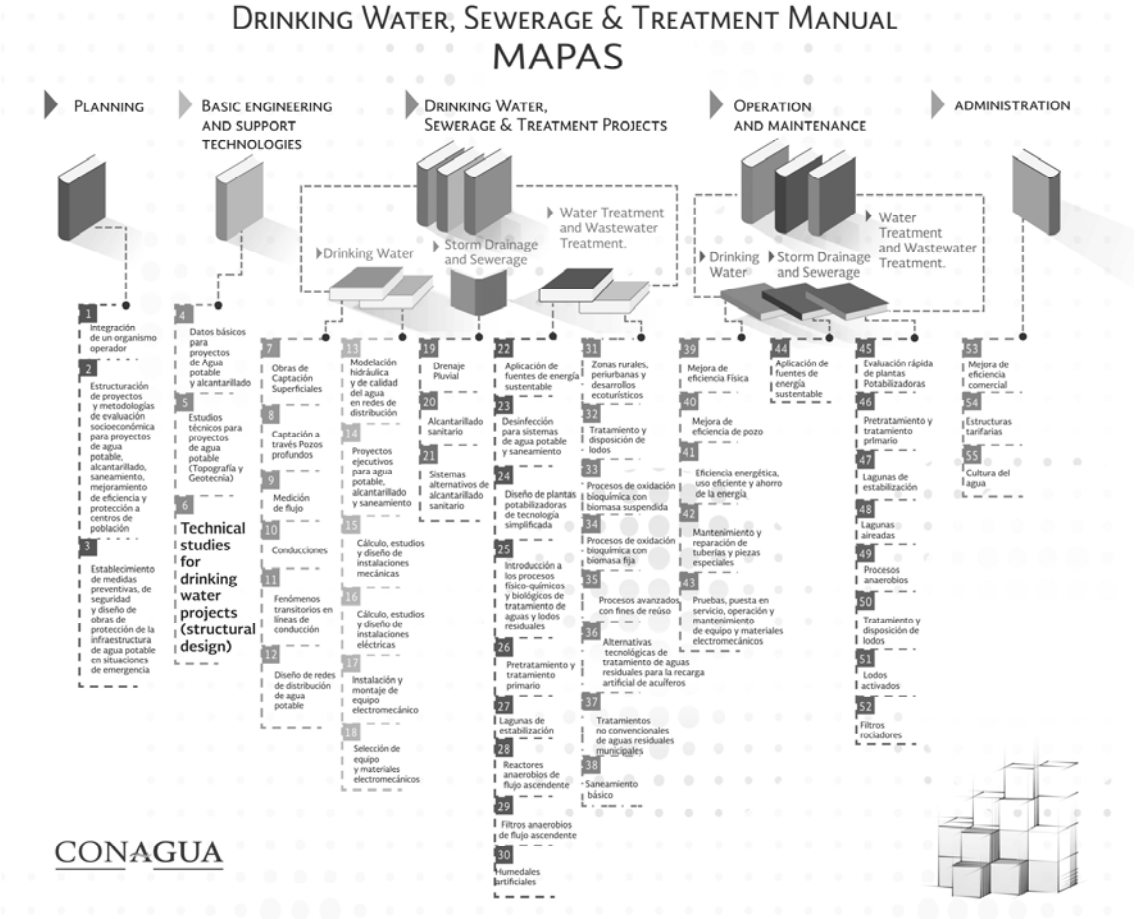

Figure 1 MAPAS structure

This structure is intended to permit the integration of a manual that is easy to understand and consult on behalf of the users and will avoid duplicities in the information of these books. The following is a description of the 5 modules and the topics that lie within each one of them.

2.1. Module 1. Planning

This module refers to the previous operations of big-vision, planning, programming, and feasibility studies which precede specific projects as well as the construction, operation, and maintenance of drinking water and sewerage. In this module, issues of programming water resources, registry of hydrosanitary infrastructure, feasibility studies, and state programs are raised; on the other hand, as part of the planning actions, steps and works are given to protect the drinking water, sewerage, and treatment systems in situations of emergency when natural disasters take place.

2.2. Module 2. Basic Engineering and support technologies

Within this module lie the initial studies necessary to carry out drinking water, sewerage, and treatment systems. The project includes previous studies on the site of application, the theoretical framework on which the design is based, the initial conditions, and the scope and limitations of the projected works.

2.3. Module 3. Drinking water, Sewerage, and Treatment projects

This module refers to the totality of the measures for the design of drinking water, sewerage, and treatment systems projects and is divided into 3 topics: drinking water, drainage, potabilization and treatment.

2.4. Module 4. Operation and Maintenance

Refers to the totality of the measures for the operation, maintenance and improvement of the drinking water, sewerage, and treatment systems.

2.5 Module 5. Management

Within this module are different topics that had not been dealt with in the MAPAS before such as: the commercial system, tariffs, human resources, materials, finances, and other topics related to water culture

As can be observed in *Figure 1* the book of technical studies for drinking water, sewerage, and treatment (Structural Design) projects can be found within module 2 and was integrated to serve as a reference for the execution of projects, new works, repairs, maintenance or extensions of the structures used in the water sector. This book contains a brief digest of the construction regulations with the most-used methodologies in Mexico and guidelines applied to structural design of the diverse infrastructure used in the water sector.

3. Background

In Mexico there is a series of regulations and standard practices that describe the design process, they reveal their own scope as well as the considerations that should be taken for the calculation of applied forces over a structure for the revision of the structural capacity of the elements that comprise them. Among the most important are:

1) The Steel Construction Manual (IMCA), from the Mexican Institute of Steel Construction

2) Official Mexican Regulation, Manuals and the Rules for the Infrastructure of Transport, from the Mexican Transport Institute and the Secretariat of Communications and Transportation

3) Civil Works Manual, from the National Electricity Commission

4) The Construction Regulation Manual for the Federal District and its Technical Complementary Rules, from the Mexico City Government.

5) Guides and Manuals for the design and constrictive processes of the Mexican Institute of Cement and Concrete

These are complemented with foreign rules and regulations which permit having an adequate quantity of information for the design process and structural revision. Among these, the following can be mentioned:

1)Regulation of construction requirement for structural concrete (ACI-318) from the American Concrete Institute

2) the Code of Specifications for Bridge Design (AASHTO-LRFD), from the American Association of State Highway and Transportation Officials

3) The rules ANSI/HI, from the American National Standard and the Hydraulic Institute

4) AWWA Manuals of Water Supply Practices, from American Water Works Association

4. Structural Design book content

The book is comprised of seven chapters that offer notions of the conditions, scope and limitations that must be considered when carrying out a structural analysis, more importantly, however, the book seeks to guide the

reader in accordance with the type of analysis that should be requested and what conditions should be taken into consideration on behalf of the people in charge of a design.

In chapter 1, there is basic information, the initial considerations as well as the most-used materials for the design and construction of structural elements; Chapter 2 addresses a structural design itself, for which there are several methodologies for the integration of the spectrum of the design and an example is given for obtaining the baseline shear and moment for an elevated tank. Moreover, the reader is induced to verify the provisions and regulations applicable in the site where the construction of the work is required. In the end, there is a brief explanation of the workings of the mathematical models used by the computer programs centered on the structural design and a series of recommendations are provided to assure their proper use. Chapter 3 describes the process proposed by the Federal Electricity Commission (CFE) in its wind-design manual (MOCV-08) of which only the static design guidelines in closed constructions and circular surfaces were extracted being that they are of most use in the sector and also the reader is encouraged to consult the manual corresponding to dynamic design for other types of constructions that do not fall into these categories. Chapter 4 presents the methodology for the design of foundations, primarily, shallow or superficial for which a complete methodology is given but it depends substantially on the study of soil mechanics so the reader is encouraged to consult the book of Technical Studies for projects related to drinking water and treatment (Topography and Geotechnics) of MAPAS: it also covers the topic of deep foundations, the design of which corresponds largely to soil mechanics, for that reason, a brief explanation of each is given, it is recommended to review the corresponding book. Chapter 5 is a collection of general recommendations for the design and construction of different works of infrastructure from the sector and are the product of the experience of the specialists in that area and the legacy of the Structural Design book recipients of the 2007 version of MAPAS. Chapter 6 offers a series of Structural Design examples through which a complete process is shown, the initial considerations and the methodology used in accordance with the considered regulation. Chapter 7 deals with the structural design of conductions and among its highlights are the recommendations for the crossing of rivers, roads and train rails and includes additional recommendations from the Conduction, Design selection and installation of steel pipes in Safety and Aqueducts books in the 2007 version of MAPAS.

5. The Structural design book and its interaction with the other books of MAPAS

Generally, but not restrictively so, the elements that comprise the extraction, conduction, and distribution systems of drinking water, collection networks, treatment systems and the regulation of wastewater as well as storm drainage networks are shown in *Figure 2*, *Figure 3* and *Figure 4*.

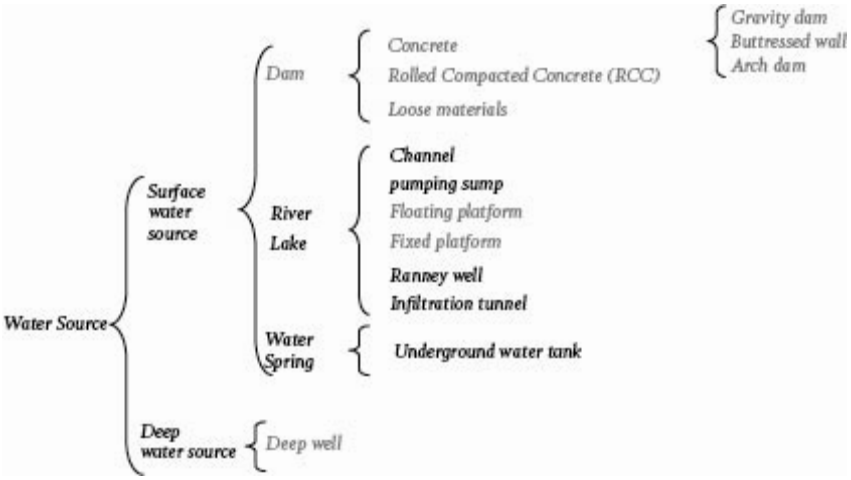

Figure 2 Primary elements that comprise hydraulic infrastructure (Collections)

Some of these elements, due to their specific characteristics, required a special structural analysis that is not properly within the regulations covered so they are not mentioned within the scope of the book, among these structures are dams and other works which are in direct contact with channels (Structures in gray from *Figure 2*). The rest of the structures can be designed, structurally speaking, with the methods and recommendations from the established regulations, nonetheless, in every work that can be found over river channels, or that is

subjected to Earth pressure, geotechnical and hydrological studies are necessary to obtain the forces that these structures will be subjected to since the regulations for a structural design don't establish how to do so, and do not give the spatial considerations that should be taken into account. The book "Technical studies for drinking water, sewerage and treatment projects: Topography and Geotechnics" covers the required studies for soil conditions, also it must be considered that soil mechanics studies will depend on the type of a design the foundation will require.

With regard to the forces resulting from water flow and the dragging of solids in rivers, they do not form part of the scope of MAPAS so it is recommended that, just like in the design of dams, special consideration be given to the recommendations in the specialized bibliography.

In the water sector there are several structures that because of their use and general characteristics do not require a complete structural analysis since these elements do not receive nor transfer forces to the soil or to other structures and for those cases there are already element types and many of these are even prefabricated, because of this, the design is limited to the selection of the size, material, specific characteristics hence, these types of works are not included in this book and are indicated in green in *Figure 3* and *Figure 4*.

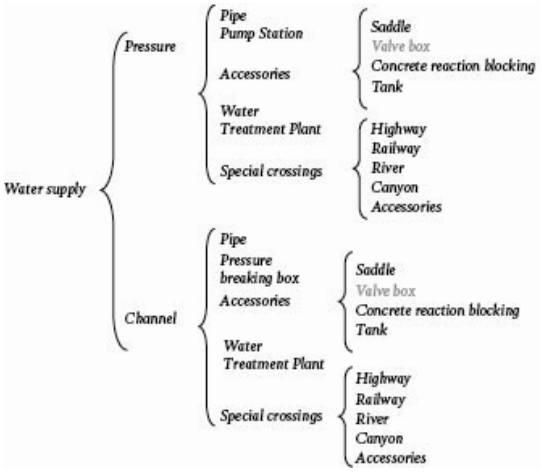

Figure 3 Primary elements that comprise hydraulic infrastructure (Conductions)

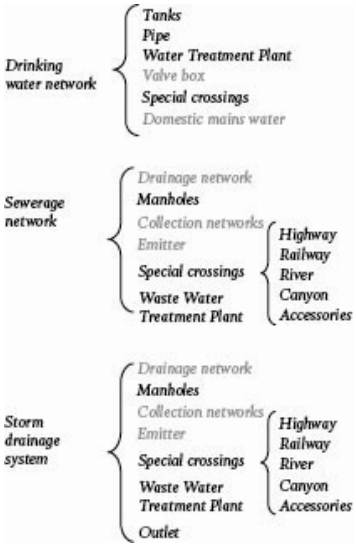

Figure 4 Primary elements that comprise hydraulic infrastructure (Collections)

In the book "Drinking Water Network Design" from MAPAS there are criteria for the selection of pipes, and valve boxes for drinking water networks. The "Sanitary Sewerage and Urban Storm Drainage" books from the MAPAS offer the criteria for the selection of pipes, manholes and pressure relief chambers. Only in particular cases where the required structure does not meet with type specifications or is subjected to additional forces, should there be a structural design and just like in the rest of the structures, should follow the methods and recommendations found in this book which are based on the corresponding regulations that are found in black in *Figure 3* and *Figure 4*.

Once these structures are a part of a system, a failure in one can cause the entire system to fail so it is important to guarantee its security and integrity during its entire lifespan, primarily, in the event of meteorological phenomena. For further reference regarding these phenomena and their effects on drinking water networks consult the book "Establishing preventive measures for the safety and Design for the protection of the drinking water infrastructure in emergency situations" in the MAPAS.

6. Relevant aspects from the Structural Design Book

In the structural design book in MAPAS there is a collection of criteria for the current regulations and the results of recent investigations. It is designed in such a way that employees from drinking water companies who are not familiar with a structural design can understand the design process, the considerations to be taken, and the presentation of the final information for its potential construction, for which charts and figures are included like the ones that can be seen in *Figure 5*. The book was created, not with the idea of creating a new regulation or design manual but rather to serve as a link between hydraulic and structural design, describing in sequential

form the structural design process depending on the type of structure and including recommendations and warnings that are the product of the experience of the personnel that operate the networks.

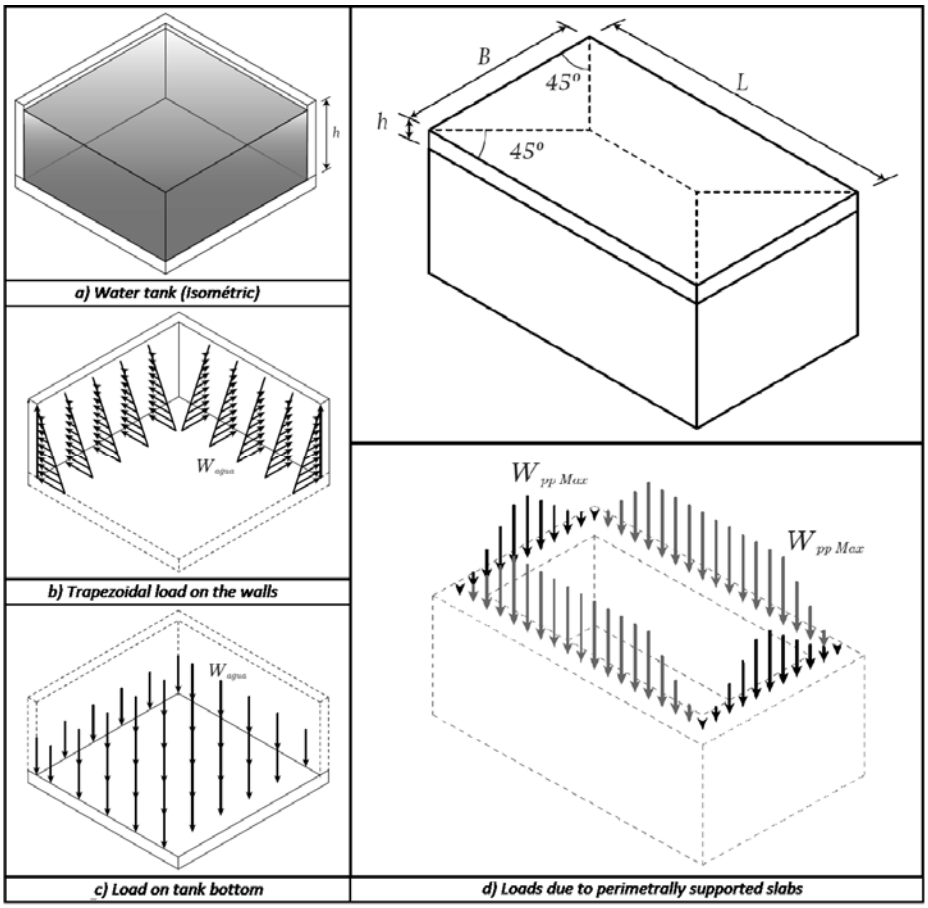

Figure 5 Example of illustrations included in the Structural Design book

6.1 Structural analysis through computer programs

In the book there is a brief explanation of the most used mathematical simulation methods for a structural design and what their scope and limitations are. It is with the objective of making the personnel that contract or carry out a structural project more aware of the implications of using a computer program to carry out the design of a structure. There is an emphasis on the fact that if the mathematical simulation models are carried out adequately, they will permit us to anticipate the behavior of the structure in the instance of different actions that it will be subjected to during its lifespan, as such it must also be stressed that these models should be done by properly trained and certified personnel in the use of the chosen program for the design.

6.2 Foundations

The book includes a chapter for the structural design of foundations which was integrated in such a way that will not only help specialists in the area to carry out these works but also serve as a good teaching tool for civil engineering students. This topic is complemented with information from the book "Technical studies for drinking water and treatment (Topography and Geotechnics)" in the MAPAS.

The information therein deals with superficial foundations in which the installed depth can be equal to or less than 4 times the width of the foundation and the deep foundations which are used when the top layers of land have little load-bearing capacity and when the use of superficial foundations can cause considerable structural damage and/or instability problems. *(See Figure 6*).

6.3 Design examples

There are three types of characteristic tanks for hydraulic infrastructure; a buried tank, a superficial tank and an elevated tank. Their design is presented in the book "Drinking water network distribution design" in the MAPAS, in the case of special tanks, their design is presented in the books corresponding to the module of municipal water treatment plant design in the MAPAS. The examples given were carried out from the structural proposal to the definition of initial actions and considerations, the calculation of the spectrum of

design, attainment of applied forces under adequate criteria and the complete design of the structural elements through a method that permits or obligates the corresponding regulation. (See *Figure 7*).

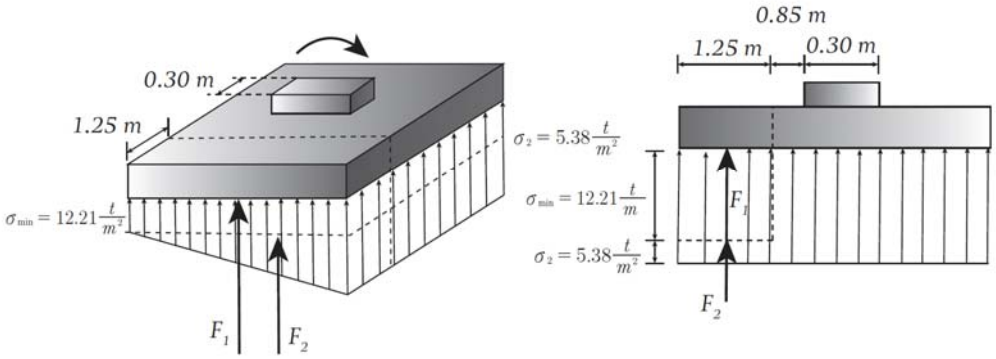

Figure 6 Fragment of an example of an isolated pad

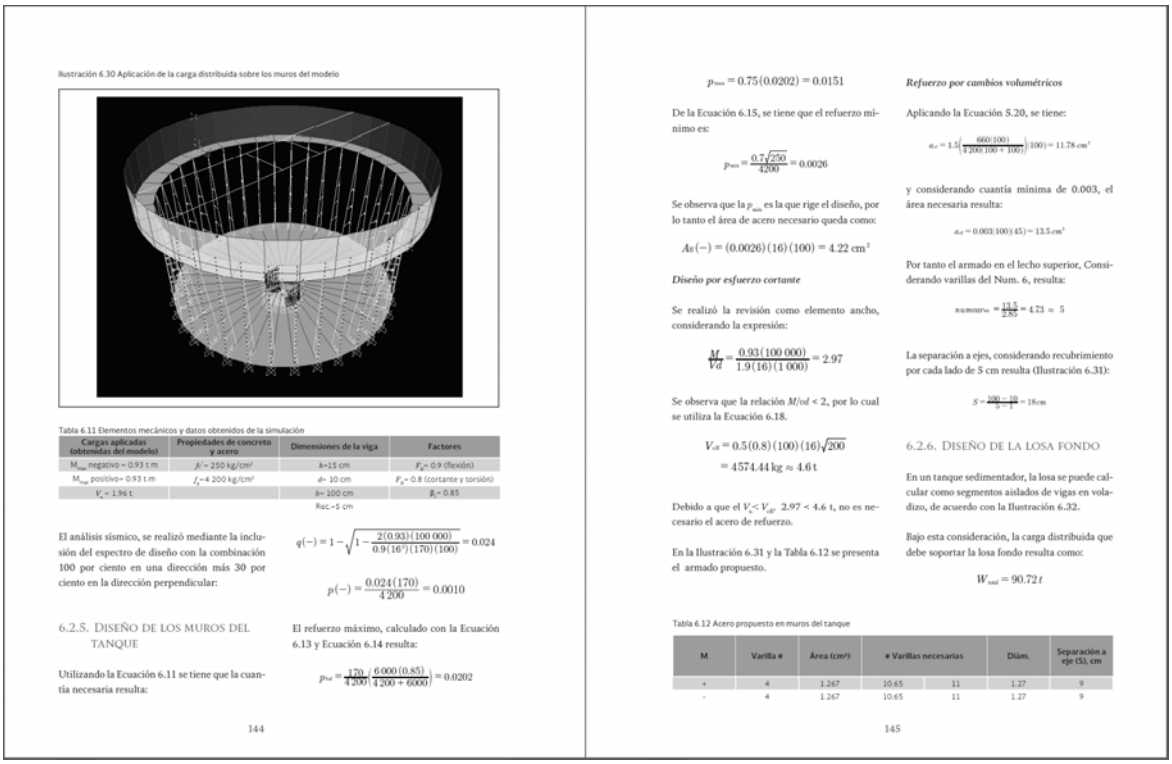

Ilustración 6.30 Aplicación de la carga distribuida sobre los muros del modelo

Tabla 6.11 Elementos mecánicos y datos obtenidos de la simulación

Cargas aplicadas (obtenidas del modelo)	Propiedades de concreto y acero	Dimensiones de la viga	Factores
M_{max} negativo = 0.93 t m	f'_c = 250 kg/cm²	h=15 cm	F_R= 0.9 (flexión)
M_{max} positivo= 0.93 t m	f_y=4 200 kg/cm²	d= 10 cm	F_R= 0.8 (cortante y torsión)
V_u = 1.96 t		b= 100 cm	β_1= 0.85
		Rec.=5 cm	

El análisis sísmico, se realizó mediante la inclusión del espectro de diseño con la combinación 100 por ciento en una dirección más 30 por ciento en la dirección perpendicular:

$$q(-) = 1 - \sqrt{1 - \frac{2(0.93)(100\,000)}{0.9(16^2)(170)(100)}} = 0.024$$

$$p(-) = \frac{0.024(170)}{4\,200} = 0.0010$$

6.2.5. Diseño de los muros del tanque

El refuerzo máximo, calculado con la Ecuación 6.13 y Ecuación 6.14 resulta:

$$p_{max} = \frac{170}{4\,200}\left(\frac{6\,000\,(0.85)}{4\,200 + 6000}\right) = 0.0202$$

Utilizando la Ecuación 6.11 se tiene que la cuantía necesaria resulta:

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$$p_{min} = 0.75(0.0202) = 0.0151$$

De la Ecuación 6.15, se tiene que el refuerzo mínimo es:

$$p_{min} = \frac{0.7\sqrt{250}}{4200} = 0.0026$$

Se observa que la p_{min} es la que rige el diseño, por lo tanto el área de acero necesario queda como:

$$As(-) = (0.0026)(16)(100) = 4.22\ cm^2$$

Diseño por esfuerzo cortante

Se realizó la revisión como elemento ancho, considerando la expresión:

$$\frac{M}{Vd} = \frac{0.93(100\,000)}{1.9(16)(1\,000)} = 2.97$$

Se observa que la relación M/vd < 2, por lo cual se utiliza la Ecuación 6.18.

$$V_{cR} = 0.5(0.8)(100)(16)\sqrt{200}$$
$$= 4574.44\,kg \approx 4.6\,t$$

Debido a que el $V_c < V_{cR}$ 2.97 < 4.6 t, no es necesario el acero de refuerzo.

En la Ilustración 6.31 y la Tabla 6.12 se presenta el armado propuesto.

Refuerzo por cambios volumétricos

Aplicando la Ecuación S.20, se tiene:

$$a_{s,c} = 1.5\left(\frac{660(100)}{4\,200(100 + 100)}\right)(100) = 11.78\ cm^2$$

y considerando cuantía mínima de 0.003, el área necesaria resulta:

$$a_{s,c} = 0.003(100)(45) = 13.5\ cm^2$$

Por tanto el armado en el lecho superior, Considerando varillas del Num. 6, resulta:

$$number_{vs} = \frac{13.5}{2.85} = 4.73 \approx 5$$

La separación a ejes, considerando recubrimiento por cada lado de S cm resulta (Ilustración 6.31):

$$S = \frac{100 - 10}{5 - 1} = 18\,cm$$

6.2.6. Diseño de la losa fondo

En un tanque sedimentador, la losa se puede calcular como segmentos aislados de vigas en voladizo, de acuerdo con la Ilustración 6.32.

Bajo esta consideración, la carga distribuida que debe soportar la losa fondo resulta como:

$$W_{total} = 90.72\,t$$

Tabla 6.12 Acero propuesto en muros del tanque

M	Varilla #	Área (cm²)	# Varillas necesarias		Diám.	Separación a eje (S), cm
+	4	1.267	10.65	11	1.27	9
-	4	1.267	10.65	11	1.27	9

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Figure 7 Fragment of an design example from a circular settling tank

6.4 Basic design recommendations for structures in the water sector

The book includes recommendations for the design and construction of specific structures such as stonework tanks, reinforced concrete tanks, and steel tanks as well as some service recommendations. All this information is the legacy of the personnel in charge of the construction and operation of the structures in the long-term. These types of recommendations are of great use for the personnel in charge of the revision of projects to be constructed, moreover, they will be useful for raising awareness in engineering students regarding the considerations which are not related to the design and which are not found specified in the regulations.

6.5 Structural design of conductions

The last chapter of the book deals with the structural design of pipework. The principal causes of failure in underground pipes during an earthquake are considered to be the vibratory movements of the ground and the fault of the terrain, for that reason the design criteria adopted is based on the fact that underground pipes should be designed to permit expansion and contraction movements through joints in such a way that they dissipate the forces generated by the earthquake. In the case of continuous systems, failures generally generated by

earthquakes are caused by bending stresses in the pipes and take place in zones close to valve boxes and intersection points. The rupture of pipes and special pieces generate a decrease in the pressure of the network since such they diminish the quality of the service. Because of this, it is absolutely necessary for them to be properly designed.

7. Conclusions

In the Manual for Drinking Water Sewerage and Treatment (MAPAS) drinking water companies are given recommendations for the creation and revision of projects, new works, reparations, maintenance or extensions of the infrastructure of the system. As part of the need to broaden the services that the operating organization delivers, the hydraulic and structural design of tanks and sumps is required, be it for the distribution of drinking water or the treatment of wastewater. It is common for the technical studies of these projects not to be carried out directly by the personnel of the organization, nonetheless, it is necessary for the book to have a reference for the elements which the designer must fulfill to guarantee an adequate design.

Consequently, the structural design book seeks to establish recommendations for the analysis, and structural design of the different types of structures required in the drinking water and sewerage systems. The most recent results of investigations and updated regulations were taken into account at the moment of the creation of this book, nevertheless, it is important to review current regulations whenever carrying out a work of infrastructure.

This book presents, in an exclusive way, the structural aspects of design which should respect the dimensionising, instrumentation and the enabling of plumbing, electro-mechanical equipment or specialized equipment. The books in the module "Drinking water networks, sewerage and treatment projects" in the MAPAS cover hydraulic and complimentary design for each type of work.

The procedures, information, mathematical models, and computer programs presented in this book are in accordance with the long-term experience afforded by specialists in the matter and the projects in which they have worked, all the same it is not intended for this book to substitute any regulation or official norm, rather it should serve as a guide for the creation and revision of the necessary studies required for the works so as to permit an adequate service to be delivered to users and to fulfill security and structural integrity specifications.

The MAPAS as a whole, is an effort on behalf of the public Federal Administration in Mexico to offer tools that permit the development of infrastructure and the improvement of drinking water, sewerage and treatment services that the population receives, additionally, it seeks to bring students closer to the activities that are carried out in the water sector. It is worth mentioning that the 55 books from the manual are freely distributed and can be consulted and downloaded on the website www.mapasconagua.net, moreover, it is intended to promote the distribution of these materials in other Spanish-speaking countries.

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