

## Foreword

The Architectural Institute of Japan set up a "Sub-Committee for Design of Storage Tanks" to provide a recommendation of the seismic design for the various types of storage tanks in common use throughout Japan. The Sub-Committee first published "Design Recommendation for Storage Tanks and Their Supports" in 1984, and amended it in the 1990 and 1996 publications. This current revised recommendation provides further guidance on seismic design methods for storage tanks based on the lateral retaining strength in the structure.

It is envisaged by publishing the English version of "Design Recommendation for Storage Tanks and Their Supports" that the above unique design recommendation will be promoted to the overseas countries who are concerned on the design of storage tanks and the activities of the Architectural Institute of Japan will be introduced them too. It is addressed how this recommendation is in an advanced standard in terms of the theory of the restoring force characteristics of the structure considering the Elephant Foot Bulge (EFB), the effect of the uplifting tank and the plastic deformation of the bottom plate at the shell-to-bottom juncture in the event of earthquake, and the design methods for the under-ground storage tanks as well. The body of the recommendation was completely translated into English but the translation of the commentary was limited to the minimum necessary parts for understanding and utilising the theories and equations in the body. The sections 2.7 Timbers and 4.9 Wooden Storage Tanks are omitted as they are not common in overseas countries. Listing of some Japanese references are omitted and some new references are added in this English version.

It is worthy of note that the contents of this recommendation have been verified and their efficacy confirmed by reference to data obtained from the tanks and silos damaged during recent earthquakes in Japan, including the Hanshin-Awaji Great Earthquake in 1995.

## Introduction

There are several types of storage tanks, e.g., above-ground, flat-bottomed, cylindrical tanks for the storage of refrigerated liquefied gases, petroleum, etc., steel or concrete silos for the storage of coke, coal, grains, etc., steel, aluminium, concrete or FRP tanks including elevated tanks for the storage of water, spherical tanks (pressure vessels) for the storage of high pressure liquefied gases, and under-ground tanks for the storage of water and oil. The trend in recent years is for larger tanks, and as such the seismic design for these larger storage tanks has become more important in terms of safety and the environmental impact on society as a whole.

The failure mode of the storage tank subjected to a seismic force varies in each structural type, with the specific coefficient of the structure ( $D_s$ ) being derived from the relationship between the failure mode and the seismic energy transferred to, and accumulated in the structure. A cylindrical steel tank is the most common form of storage tank and its normal failure mode is a buckling of the cylindrical shell, either in the so called Elephant Foot Bulge (EFB), or as Diamond Pattern Buckling (DPB). The  $D_s$  value was originally calculated by reference to experimental data obtained from cylindrical shell buckling, but was later re-assessed and modified based on the restoring force characteristics of the structure after buckling. Those phenomena at the Hanshin-Awaji Great Earthquake were the live data to let us review the  $D_s$  value. For the EFB, which is the typical buckling mode of a cylindrical shell storage tank for petroleum, liquefied hydrocarbon gases, etc., it became possible to ascertain the buckling strength by experiments on a cylindrical shell by applying an internal hydrodynamic pressure, an axial compressive force, and a shear force simultaneously. Details of these experiments are given in Chapter 3.

The seismic design calculations for other types of storage tanks have been similarly reviewed and amended to take into account data obtained from recent experience and experiments.

For above-ground vertical cylindrical storage tanks without any restraining element, such as anchor bolts or straps, to prevent any overturning moment, only the bending resistance due to the uplift of the rim of bottom plate exists. This recommendation shows how to evaluate the energy absorption value given by plasticity of the uplifted bottom plate for unanchored tanks, as well as the  $D_s$  value of an anchored cylindrical steel-wall tank.

As the number of smaller under-ground tanks used for the storage of water and fuel is increasing in Japan, the Sub-committee has added them in the scope of the recommendation and provided a framework for the seismic design of under-ground tanks. The recommendation has accordingly included a new response deformation method and a new earth pressure calculation method, taking into account the design methods adopted by the civil engineering fraternity.

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