PREFACE

By Michael O'Rourke

Buried pipeline systems are commonly used to transport water, sewage, oil, natural gas and other materials. In the conterminous United States, there are about 77,109 km (47,924 miles) of crude oil pipelines, 85,461 km (53,114 miles) of refined oil pipelines and 67,898 km (42,199 miles) of natural gas pipelines (FEMA, 1991). The total length of water and sewage pipelines is not readily available. These pipelines are often referred to as "lifelines" since they carry materials essential to the support of life and maintenance of property. Pipelines can be categorized as either continuous or segmented. Steel pipelines with welded joints are considered to be continuous while segmented pipelines include cast iron pipe with caulked or rubber gasketed joints, ductile iron pipe with rubber gasketed joints, concrete pipe, asbestos cement pipe, etc.

The earthquake safety of buried pipelines has attracted a great deal of attention in recent years. Important characteristics of buried pipelines are that they generally cover large areas and are subject to a variety of geotectonic hazards. Another characteristic of buried pipelines, which distinguishes them from above-ground structures and facilities, is that the relative movement of the pipes with respect to the surrounding soil is generally small and the inertia forces due to the weight of the pipeline and its contents are relatively unimportant. Buried pipelines can be damaged either by permanent movements of ground (i.e. PGD) or by transient seismic wave propagation.

Permanent ground movements include surface faulting, lateral spreading due to liquefaction, and landsliding. Although PGD hazards are usually limited to small regions within the pipeline network, their potential for damage is very high since they impose large deformation on pipelines. On the other hand, the wave propagation hazards typically affect the whole pipeline network, but with lower damage rates (i.e., lower pipe breaks and leaks per unit length of pipe). For example, during the 1906 San Francisco earthquake, the zones of lateral spreading accounted for only 5% of the built-up area affected by strong ground shaking. However, approximately 52% of all pipeline breaks occurred within one city block of these zones, according to T. O'Rourke et al., (1985). Presumably the remaining 48% of pipeline damage was attributed to wave propagation. Hence, although the total amount of damage due to PGD and wave propagation was roughly equal, the damage rate in the small isolated areas subject to PGD was about 20 times higher than that due to wave propagation.

Continuous pipelines may rupture in tension or buckle in compression. Observed seismic failure for segmented pipelines, particularly large diameters and relatively thick walls, is mainly due to distress at the pipeline joints (axial pull-out in tension, crushing of bell and spigot in compression). For smaller diameter segmented pipes, circumferential flexural failures (round cracks) have also been observed in areas of ground curvature.

This monograph reviews the behavior of buried pipeline components subject to permanent ground deformation and wave propagation hazards, as well as existing methods to quantify the response. To the extent possible and where appropriate, the review focuses on simplified procedures which can be directly used in the seismic analysis and design of buried pipeline components. System behavior of a buried pipeline network is not discussed in any great detail. Where alternate approaches for analysis or design are available, attempts are made to compare the results from the different procedures. Finally, we attempt to benchmark the usefulness and relative accuracy of various approaches through comparison with available case histories.

This monograph is divided into twelve chapters. Chapter 1 reviews seismic hazards and the performance of buried pipelines in past earthquakes. Chapter 2 describes the different forms of permanent ground deformation (surface faulting, lateral spreading, landsliding), and presents procedures to quantify and model both the amount of PGD as well as the spatial extent of the PGD zone. Chapter 3 reviews seismic wave propagation and presents procedures for estimating ground strain and curvature due to travelling wave effects. Chapter 4 presents the failure modes and corresponding failure criteria for buried pipelines subject to seismic effects. Chapter 5 reviews commonly used techniques to model the soil-pipe interaction in both the longitudinal and transverse directions.

Chapters 6 and 7 present the response of continuous pipelines subject to longitudinal PGD and transverse PGD respectively, while Chapter 8 discusses pipe response due to faulting. Chapter 9 presents the response of segmented pipelines subject to permanent ground deformation. Chapters 10 and 11 discuss the behavior of continuous and segmented pipeline components subject to seismic wave propagation. Chapter 12 presents current countermeasures to reduce damage to pipelines during earthquakes.