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Failure analysis of a welded steel pipe at Kullar fault crossing

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ABSTRACT

The seismic response of a 2200-mm-diameter welded steel pipe at strike slip Kullar fault crossing in Izmit, Kocaeli during 1999 Kocaeli earthquake is investigated. The pipe was crossing the fault-line with an angle of 55° and suffered leaks due to 3.0 m of right lateral movement of fault, which imposed compressive axial strain in the pipe. The backfill material of the trench was native soil which was non-homogenous (soft and stiff clay) with respect to fault line-soft material on the North side, stiff material on the South side. Field observations revealed two major wrinkles with finger width cracks and a minor wrinkle on the soft soil side of the fault. Large plastic strains and local folding were observed at wrinkles due to compressive strains. The case is known as one of the best documented fault crossing examples.
The failure behavior of the Thames water pipe during 1999 Kocaeli earthquake is simulated by utilizing a 3D nonlinear continuum FE model. The numerical model considers contact surface at soil pipe interface and performs large deformation analyses of the pipe. The locations of wrinkles as well as axial displacements/rotations demands due to fault rupture are predicted. It is observed that once wrinkle initiates, strain in the pipe away from the wrinkle reduces after initial local buckling and additional shortening of the pipeline tends to accumulate at the wrinkle causing large plastic strains and rotation demands associated with fault rupture, an observation consistent with field observations and 2005 ALA guidelines.

1. Introduction

Welded steel pipelines are commonly used in transmitting oil, gas and water from the sources to end users. Such high quality pipes usually do not suffer damage due to wave propagation but can be damaged by permanent ground deformations (PGD) caused by surface faulting, landslides and liquefaction induced lateral spreads. Among these, the fault crossing hazard is considered as one of the most severe as such abrupt ground deformations (step loadings) may cause excessive axial strains in the pipe wall and lead to failure.

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The main aim in the design of buried pipelines in fault crossing areas is to reduce the risk of damage due to fault displacements by minimizing the pipe strains. Axial and lateral nonlinear soil springs are used to represent the soil resistance to pipe movement in numerical modeling. The design strategy is to promote tension as opposed to compression in the pipe and to adjust the orientation angle, slip direction, pipe thickness and soil backfill material of the soil so as to minimize axial strains in the pipe [1–4]. The compression failure of the pipeline takes place at lower offset values than failure in tension [5] and therefore it should be avoided in the design of pipes. However, pipe orientation and crossing angles are often governed by right-of-way constraints which are also included in the current design codes. Nevertheless, in the past, relevant provisions or guidelines were not available in pipeline design practice. A simplified model has also been developed by Uckanet al. which is commonly needed for engineering practices to determine the seismic demand of steel pipes at fault crossings [6].

The behavior of steel pipes under compression is quite complex, associated with a series of events that may lead to pipeline failure. Therefore, case studies on pipe wall failure are particularly important to understand the actual behavior of pipes subjected to fault displacements. The behavior of a pipe segment subjected to compressive loading has been the subject of several publications in the past. Notable contribution on the buckling failure of steel tubular members and pipes subjected to pure axial compression have been reported by Reid [7], and more recently by Tutuncu [8] and Bardi and Kyriakides [9]. The bending response and buckling of tubulars have been reported by Ju and Kyriakides [10], Karamanos and Tassoulas [11] and recently in a study by Sarvanis et al. [12] of the behavior of large-diameter spiral-welded pipes. Furthermore, the effect of surrounding soil restrain on the buckling strength of buried pipelines has been studied by Youn and Kyriakides [13].

In the 1999 Kocaeli earthquake, the main 2200-mm-diameter butt-welded steel Thames water transmission pipeline experienced major damage and leaks due to rupture of the strike slip fault, a branch of the Sapanca segment of the North Anatolian Fault (NAF). The pipe was constructed one year before the 1999 Kocaeli earthquake. It was crossing the fault with an angle of 55° and subjected to net compression due to 3 m of right lateral slip. It was a severe situation for the pipeline. As a result, the pipe suffered two major and one minor local buckle, shortened by 1.7 m, underwent large axial plastic strains. However, it stayed in service after the earthquake before the repairs were made [14].

A number of researchers investigated the performance of the Thames water pipe [14–18]. Liu et al. used a shell model for equivalent boundary [18].Takada used simplified methods to estimate the maximum strain considering material and geometric nonlinearities [19]. Liu et al. investigated the relation between the maximum strain and bending angle was studied by using beam shell hybrid finite element model [20]. They used equivalent soil springs, adopted from ASCE 1984 [21], to consider the effects of soil resistance to pipe movement. The effects of internal pressure were taken into account indirectly by increasing the pipe

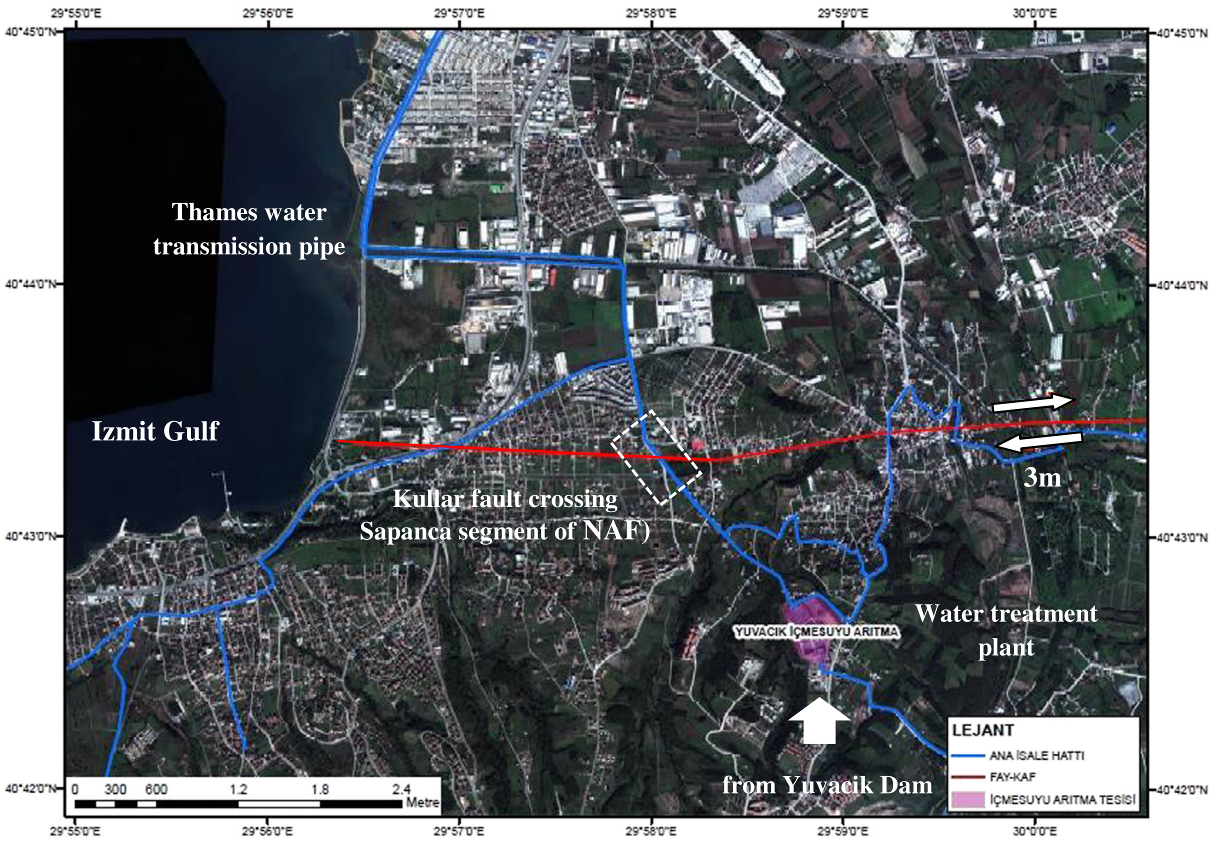

Fig. 1. The Thames water transmission pipeline at Kullar fault crossing, (Satellite image by ISU).