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BURIED PIPELINE ACROSS SAN ANDREAS FAULT

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SUMMARY

Pipeline segments have been placed across a strand of the San Andreas Fault near Parkfield, CA in order to capitalize on the predicted recurrence of the 1966 Parkfield-Cholame earthquakes. Active and passive instrumentation will provide data for evaluating seismic performance of pipelines, including design and analysis methods.

INTRODUCTION

Surface expressions of fault movement such as lateral offsets and ground rupture and lateral spreading pose major threats to pipelines. Models of pipeline behavior at fault crossings provide conservative designs in cases where detailed geotechnical information is lacking (Refs. 1 and 2). The predicted recurrence of the 1966 Parkfield-Cholame earthquakes (Refs. 3 and 4) provide an opportunity to study the assumptions of these models. A maximum of four inches surface lateral offset is expected to accompany the earthquake. Instrumentation has been installed to measure the lateral offset and the deformation of joints and strains in the pipes.

In addition to lateral offset, pipelines are exposed to ground shaking due to wave propagation. Models have also been proposed to support design of pipelines exposed to shaking (Refs. 5 and 6). Such models assume that the ground deformation is due to a wave train propagating with a predominant frequency and group velocity and is imposed on the pipeline with negligible dynamic pipe-soil interaction. In the present experiment, local ground shaking is measured by three seismometers, which were contributed by Kyoto University. These are placed within the zone of expected surface rupture.

EFFECTS OF LATERAL OFFSET AND WAVE PROPAGATION ON PIPELINES

The approach of Ref. 1 was developed for continuously welded steel pipes and was initially applied to design of the Trans-

Alaska pipeline. The pipe is oriented with respect to the fault strike such that offset puts the pipe in tension. Flexure of the pipe is neglected. The geometry envisioned in the model is shown in Fig. 1.

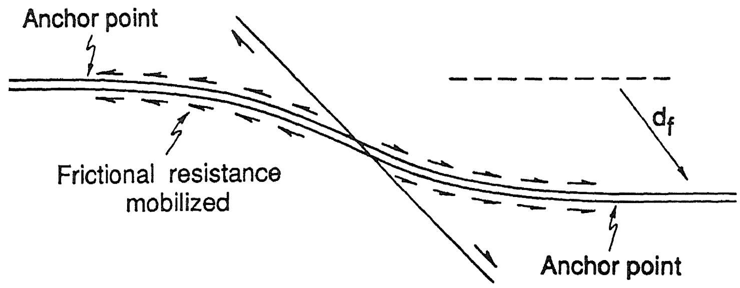

Figure 1. Continuous pipeline envisioned in Newmark-Hall design approach.

An effective anchor length is defined as the distance away from the fault over which friction between the soil and pipe is mobilized, meaning that the frictional stresses acting over this length are constant and equal to the maximum that confinement will support. The approach of Ref. 1 has been amended in Ref. 2 to account for increased frictional resistance that occurs near the fault crossing due to local flexure of the pipe. The seismic performance of ductile iron pipes is related to the capacity of joints to accommodate extension and rotation. Modern ductile iron pipe for water distribution uses rubber gasket push-on joints which can accommodate several inches of extension and up to about 5° of rotation without leaking (Ref. 7).

Aspects of wave propagation models that require further study are the predominant wavelength (which may be derived from the predominant frequency and the group velocity) and the direction of propagation. Studies aimed at identifying predominant frequencies and their group velocities include Refs. 5 and 8. An example of how such information is used to examine the serviceability of pipeline networks following an earthquake is provided in Ref. 9, which describes the responses of networks subjected to vertically propagating SH waves.

For continuously welded pipelines, experimental data are needed to correlate group velocity and particle velocity data with strain in the pipe and to measure the effective anchor distance from surface rupture where lateral offset has occurred. For pipelines with flexible joints, data are needed to show how lateral offset is accommodated at the joints in combined extension and rotation.

PARKFIELD PIPELINE EXPERIMENT

The site of the present field test is Owens Pasture, which is 2 km N.W. of Parkfield in central California. Ground rupture was observed there in the June-August 1966 Parkfield-Cholame earthquakes. A USGS creepmeter in the pasture indicates that about 11 mm of fault creep per year is occurring between vaults located about 10 m apart.

To find the most likely zone of surface rupture, trenches were dug orthogonally to the assumed fault strike at the north and south ends of the pasture. The sides of the trenches were inspected for fault gouge and other subsurface evidence of localized displacement. Weak evidence of such a zone was found in the north trench; no evidence was found in the south trench. In order to define the strike, surface evidence was also considered. The strike is assumed to be as shown in Fig. 2. Recent survey data indicates that the present zone of maximum creep lies about 20 m to the south of the zone assumed a year ago.

The design models referred to above specify that the pipeline should be put into tension by the fault offset. Accordingly, a welded steel pipeline segment has been constructed and instrumented which will be put into tension by right lateral strike slip. In Fig. 2, this segment is designated T and is oriented at 40° to the assumed fault strike. Strain gages measure bending in

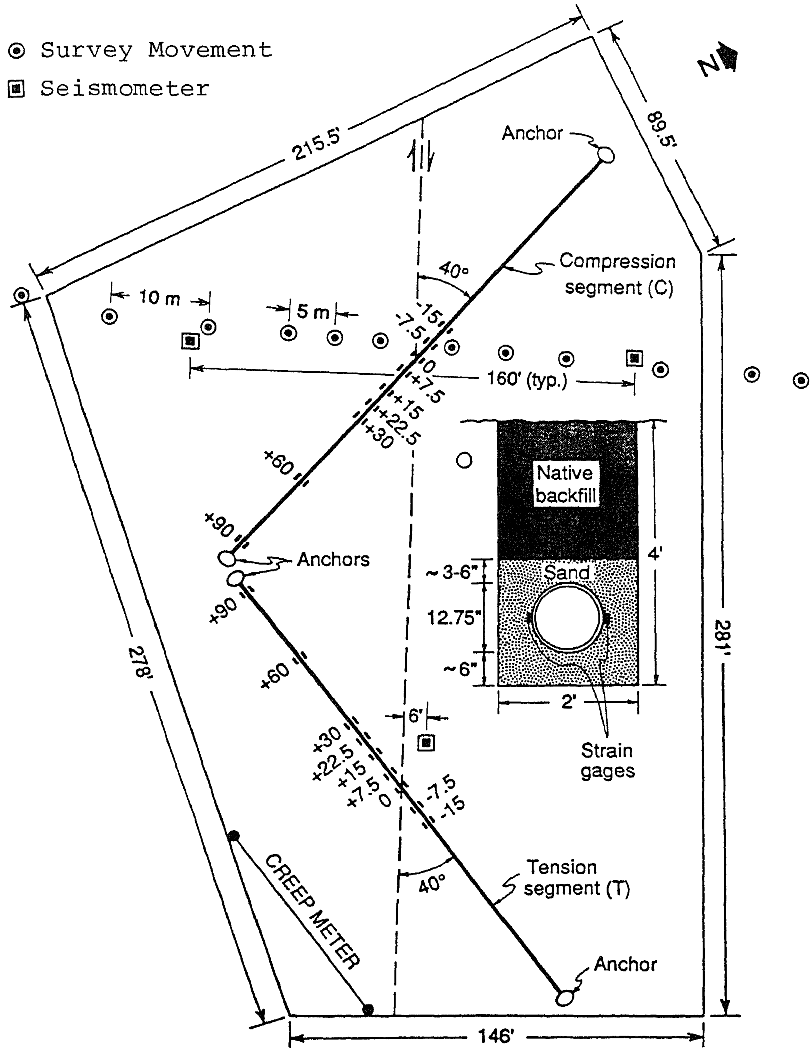

Figure 2. Orientation and strain gage locations, welded steel pipe segments.

the horizontal plane and extension. A companion segment, designated C, is oriented at -40°. to the fault strike and will be subject to compression. Steel pipe segments were delivered in 40 ft lengths and joined by full penetration welds.

Eight ductile iron segments were also emplaced; see Fig. 3. Each segment is comprised of two or three 18 ft. pipe lengths oriented at 60° and 30° to the fault strike. Two-length segments are placed such that the joint is at the assumed fault crossing; three-length segments are placed such that the assumed fault crossing is at the middle of the middle length.

The pipe segments were laid in a two foot wide trench excavated to a depth of four feet. The trenches were backfilled with river sand up to three to six inches above the crown. Native soil from the trench excavation was replaced and compacted by driving the tractor-backhoe over it. All pipeline segments have restrained ends provided by concrete anchors in order to simulate a great length of pipe.

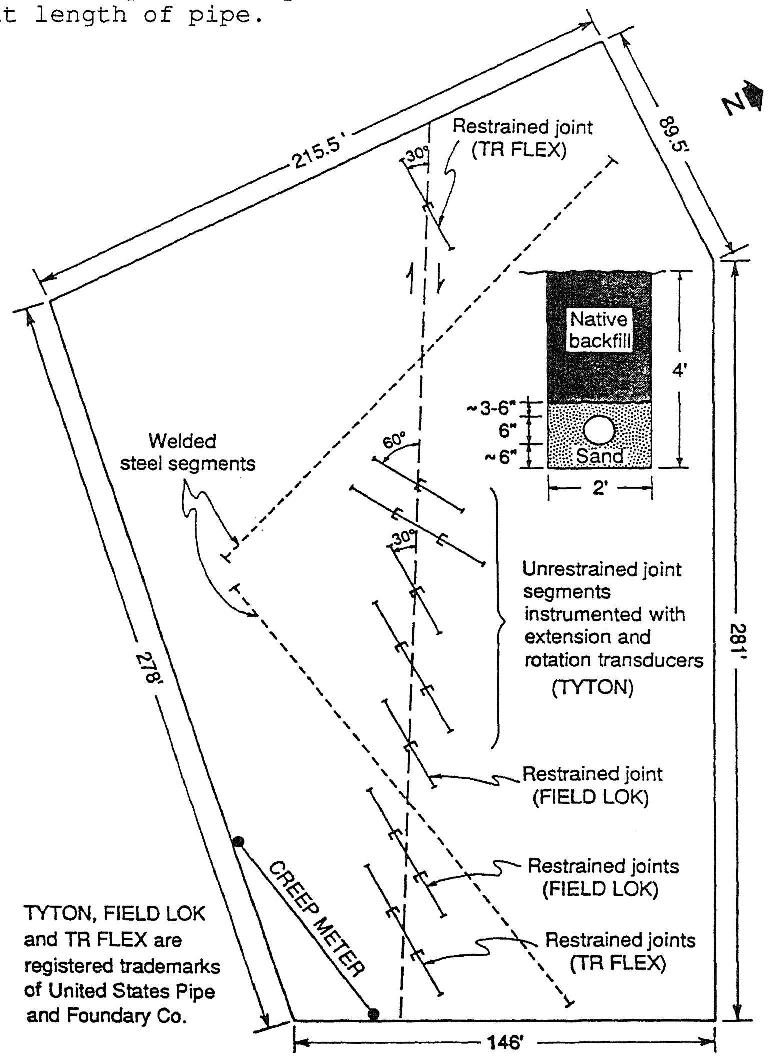

Figure 3. Orientation and joint types for iron pipe segments.

Passive instrumentation consists of survey monuments which have been placed roughly perpendicular to the fault strike. These are surveyed every three to four months by USGS. Active instrumentation on the steel pipes consists of welded strain gages. Thermocouples are provided as an aid to temperature compensation. The ductile iron pipes are instrumented with displacement transducers. Each joint has one transducer to measure extension and another attached to an arm to measure rotation. The assembly is covered by a smooth shroud to keep soil from interfering with the movement of transducer components.

Three 3-axis seismometers have been supplied by Kyoto University under a US-Japan cooperation agreement developed for the present project. Each is mounted on a concrete pad, and is self-recording. A link to the data logger permits common timing to be established between the strains on the welded steel pipe, relative displacements at joints in ductile iron pipe and the ground shaking as recorded by the seismometers.

The data logger, a Campbell-Scientific CR-7, is divided into two recording units, each of which is activated when one of the six trigger channels exceeds a pre-determined threshold value corresponding to earthquake-induced strain. A number of 60-second events can be recorded.

STATUS AND FUTURE PLANS

Seismic activity has been low in Parkfield recently. Long term fault creep displacements recorded north of Owens Pasture are of order 22 mm/year; at Owens Pasture, the rate is 11-13mm/ year; south of Parkfield, the rates are 3-10 mm/year (Ref. 10). Future activities include developing a data interpretation plan in cooperation with Japanese workers for relating seismometer records to pipe strains and joint deformations. A finite element analysis is being considered which will include the details of the anchors and 3-D pipe-soil interaction effects.

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