NATIONAL CENTER FOR EARTHQUAKE
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State University of New York at Buffalo

PIPELINE EXPERIMENT AT PARKFIELD, CALIFORNIA

by

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Technical Report NCEER-87-0016

September 15, 1987

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ABSTRACT

Welded steel and ductile iron pipeline segments have been constructed at Owens Pasture near Parkfield, California, in anticipation of a Magnitude 6.0 earthquake on the San Andreas Fault. Strain gages attached to the welded steel segments will provide data for assessing current design approaches at fault crossings. Relative rotation and extension transducers at the joints of ductile iron pipe will indicate how the fault offset is accommodated by joint movement. The present experiment is being closely coordinated with the earthquake prediction project of the US Geological Survey.

ACKNOWLEDGMENTS

The cooperation and assistance of the US Geological Survey has been indispensable to this experiment. The assistance of US Pipe and Foundry Co. of Union City, California and Birmingham, Alabama in supplying ductile iron pipe segments, joints, transportation and on-site assistance in laying the pipe is gratefully acknowledged. The assistance of Northwest Pipe and Casing Co. of Portland, Oregon in supplying steel pipe segments and transportation is also gratefully acknowledged.

Dr. Thomas D. O'Rourke, Associate Professor of Civil Engineering at Cornell University, is consultant to Weidlinger Associates on this project. His contributions in deciding orientation of the welded steel pipe and instrumentation have increased greatly the potential value of the experiment.

Torque and Tension Systems of Campbell, California is subcontractor to Weidlinger Associates for instrumentation and data recording. Mr. Jack Jones is responsible for design and supervision. Mr. Craig Vossbrinck is responsible for installation.

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SECTION 1
INTRODUCTION

The predicted recurrence of the 1966 Parkfield-Cholame earthquakes provides an opportunity to investigate the performance of underground pipelines subjected to lateral fault offsets [1, 2]. Two types of pipelines, ductile iron with both flexible and restrained joints and welded steel, have been placed across the fault using standard construction practice. Strain gages and displacement and rotation transducers will provide data concerning pipe-soil interface slip and rotation or extension of flexible joints.

The site of the field experiment is Owens Pasture located about two km west of Parkfield, California. It is collocated with a creepmeter experiment being conducted by the US Geological Survey, which helps to locate the fault strand and to monitor precursors of the main earthquake.

As part of the pipeline project, exploratory trenches were dug roughly perpendicular to the local strike of the San Andreas Fault in order to expose a fault gouge zone. With the aid of a member of the US Geological Survey, Dr. John Sims, this zone was tentatively identified on the north side of the pasture. Clear evidence was lacking in the trench on the south side, so reliance was placed on the creepmeter and morphological features to identify the fault strand on the south side.

The project has been under way for about three months as of the writing of this report. Accomplishments include the following:

1. Site identified and lease procured.
2. Two welded steel segments, each 200 ft long, constructed, instrumented with strain gages and buried.
3. Eight ductile iron segments, varying from 36 to 54 ft long, assembled and placed. Instrumentation is in progress.
4. Provision for data recording equipment (cables, shed) constructed.

5. Through the American Iron and Steel Institute and Ductile Iron Pipe Research Association, liaison was established with Northwest Pipe & Casing Co. and U.S. Pipe, respectively, who donated pipe and advised on construction and emplacement procedures; U.S. Pipe representatives helped with assembling joints in the field.

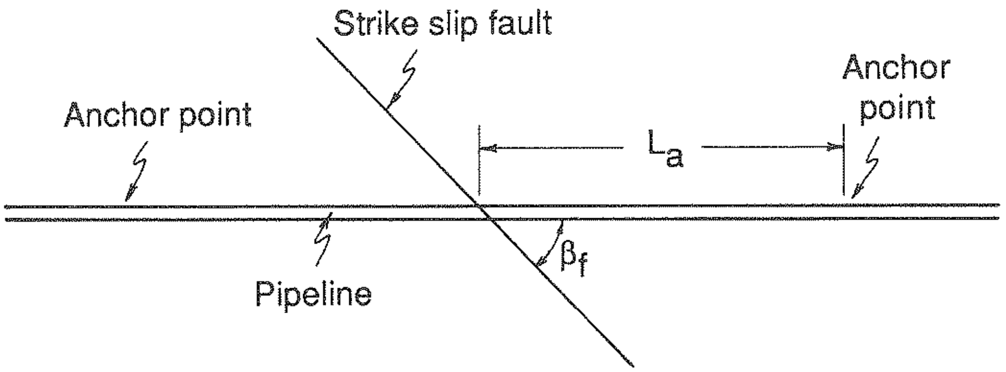
The next major step in the project, after completing instrumentation and burying the ductile iron pipe, is to acquire data recording equipment, attach the cables and develop a monitoring procedure in concert with USGS.

SECTION 2
BRIEF REVIEW

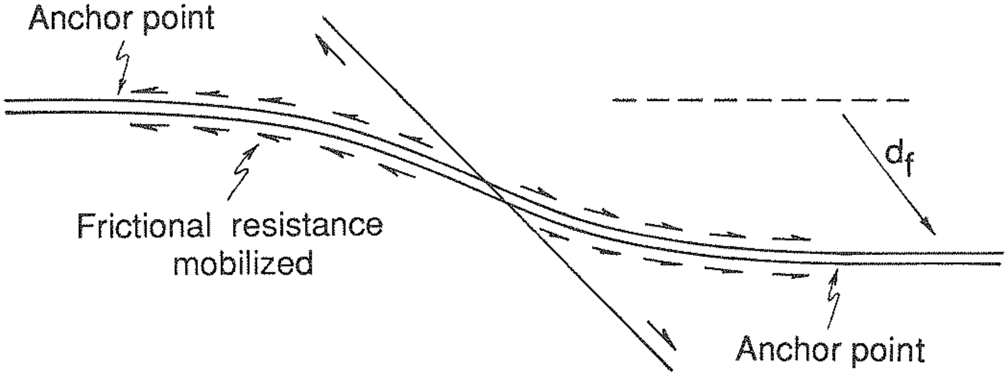
For the purpose of understanding pipeline performance, earthquake ground shaking is divided into wave propagation effects and ground rupture effects [3, 4, 5]. The latter may include surface faulting, shattered earth, liquefaction and lateral spreading of near surface soil deposits. Welded steel pipelines crossing zones of fault offsets have experienced weld failures; jointed pipelines with stiff joints, such as cement or lead caulking, have also failed [5, 6].

2.1 Design Methods and Assumptions

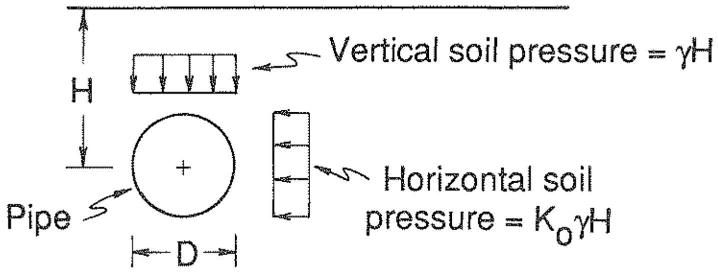
Design methods to prevent catastrophic failure of welded steel pipelines have been proposed and have been applied in such cases as the Alyeska or Trans Alaska pipeline where lateral offsets of up to twenty feet are considered. The approach of Newmark and Hall [7] was adopted to develop seismic mitigation procedures in Alaska and other fault crossings. In this approach, the pipe is oriented with respect to the fault strike such that fault offset puts the pipe in tension. The geometry envisioned in the model is shown in Fig. 2-1. An effective anchor length is defined as the distance away from the fault over which friction between soil and pipe are mobilized. The average plastic strain in the pipe depends on the properties of the pipe (Fig. 2-2) (thickness, yield strength), the characteristics of the soil (friction, unit weight) and the fault offset. The Newmark-Hall approach has been amended by Kennedy-Chow-Williamson [8] to take into account the increased frictional resistance that occurs near the fault crossing. Flexural as well as extensional strains in the pipe are also considered. The results, as measured by the effective anchor length, differ dramatically even though the two approaches share many common assumptions. For the pipeline considered in the present project (diameter = 1 ft, thickness = .1046 in, yield strength = 33,000 psi; fault displacement = 4 in, depth of burial = 3 1/2 ft), the Newmark-Hall approach indicates an anchor length of 225 ft for a 40° crossing, whereas the Kennedy-Chow-Williamson approach indicates about 20 ft. A major goal of the present field test is to provide data that will allow these and other design and assessment methods to be evaluated.



a) Before Fault Movement



b) After Fault Movement



c) Transverse Cross-Section

Figure 2-1. **Plan and Sectional Views of Continuous Pipeline Envisioned in Newmark-Hall Design Approach**

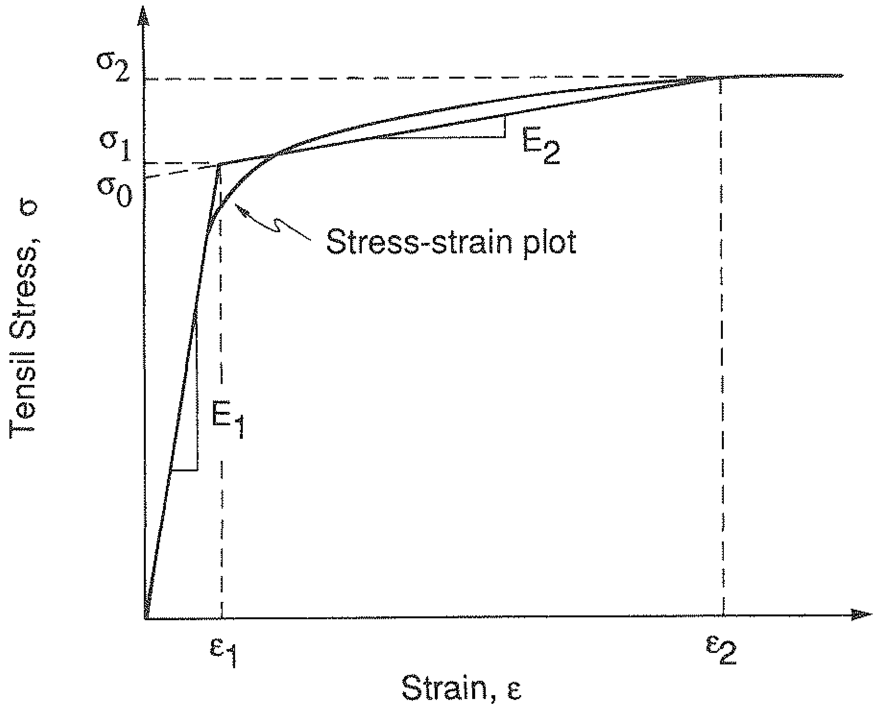


Figure 2-2. Steel Stress-Strain Relation Assumed in Newmark-Hall Design Approach

The seismic performance of ductile iron pipes is related to the capacity of joints to accommodate relative displacement and rotation. Reaches of pipe are considered to be much stiffer and stronger than flexible joints. In regions of unstable ground, replacement of flexible joints with restrained joints leads to a more rigid pipeline system resembling the welded steel pipeline. A major advantage of modern ductile iron pipe for water distribution is that it can be laid without requiring highly skilled labor to make the joints, which in most cases are of the rubber gasket push-on type. In addition, the flexible joints can accommodate several inches of extension and up to about five degrees of rotation without leaking; this allows for settlement under ordinary traffic loads as well as for fault movement. Under conditions of fault movement which exceed these reserves, leakage and joint rupture are expected. One aspect of joint behavior in situ that is not well-understood is how combinations of extension and rotation interact to influence joint capacity; laboratory studies conducted at Cornell University indicate interaction decreases capacity [9]. Under circumstances where excessive extensions and/or rotations may occur, for example at an embankment, rigid couplings are used. The seismic performance of these couplings will be evaluated in the present study. The second major purpose of the project is to provide data for evaluating the performance of flexible joints in ductile iron pipe under conditions of combined rotation and extension and to investigate the performance of rigid joints in fault zones.

2.2 Surface Expression of Fault Movement

In discussions of the design methods by others and in the present report, it is convenient to refer to the fault zone as a single, plane feature of negligible width. This idealization is accurate enough for many purposes, yet it is a simplified view of a complex situation. First, the focal depth of the 1966 earthquake is estimated to have been 8 km [10]. Lateral offset at the surface is merely an expression of deeper fault movement. Surface rupture in Owens Pasture may be due to one or more of several strands of the fault trace. The creep rate in Owens Pasture is low relative to rates measured to the north and south, suggesting that the creepmeter may not embrace all fault strands in the neighborhood; other strands may lie outside the creepmeter or even outside the Pasture. At stations elsewhere in the Parkfield-Cholame area, 90% of the creep that is taking place does so over a zone about 10 meters wide. The point of maximum creep, one indication of where surface rupture may occur in the earthquake, wanders in this zone. Another indication of the likely location of ground movement is the near surface zone of fault gouge, in this area about one meter wide. Taken together with morphological evidence and creepmeter data and physical observation of surface rupture in past earthquakes, the approximate location of a rupture zone has been predicted for the purpose of locating the pipe segments. Confidence in the details of such predictions cannot be assessed.

SECTION 3
FIELD TEST

3.1 Owens Pasture Site

In the present field test, segments of welded steel and ductile iron pipe are laid where they may be intersected by surface ruptures caused by movement of the San Andreas Fault near Parkfield, California. Ground rupture was observed in Owens Pasture in the June-August 1966 Parkfield-Cholame earthquakes. The US Geological Survey has identified this site as a possible zone of surface rupture during a recurrence of that earthquake sequence, which is predicted to occur in the near future. Owens Pasture, Fig. 3-1 is level and is bounded on the north by a range of hills and on the east by a swale and shallow pond which is dry most of the year. The soil is adobe clay mixed with pebbles and gravely sediments washed down from the hills. There are no obvious features that mark the location of the fault strand in the Pasture. A USGS creepmeter in the southeast corner of the Pasture is oriented at 30° to the assumed strike at that location. It indicates that about 11 mm of fault creep per year is occurring between the two creepmeter vaults. This is substantially less than the value of 15-18 mm per year that is observed at sites to the south and is also less than the 25 mm per year that is observed at the Middle Mountain site to the north. The relatively low value of fault creep at this site is not fully understood by USGS; it may be due to locating the creepmeters only partially inside the creep zone or to division of the surface expression of the fault into multiple strands, only one of which intersects the creepmeter. These and other possibilities can be evaluated with greater certainty only after the earthquake.

To improve chances that pipeline segments will be intercepted by lateral offset accompanying the earthquake, trenches were dug as shown in Fig. 3-2. These were four feet deep, three feet wide and were approximately at right angles to the assumed strike of the fault. A member of USGS, Dr. John Sims, agreed to inspect the trenches for fault gouge and other subsurface evidence of localized displacement offset. According to him, such evidence ideally is found in a zone about one meter wide. Since the fault zone acts as a barrier to water and water borne sediments, the zone may be marked by a change in color of soil and by the abrupt disappearance of sand and gravel lenses, which in the present

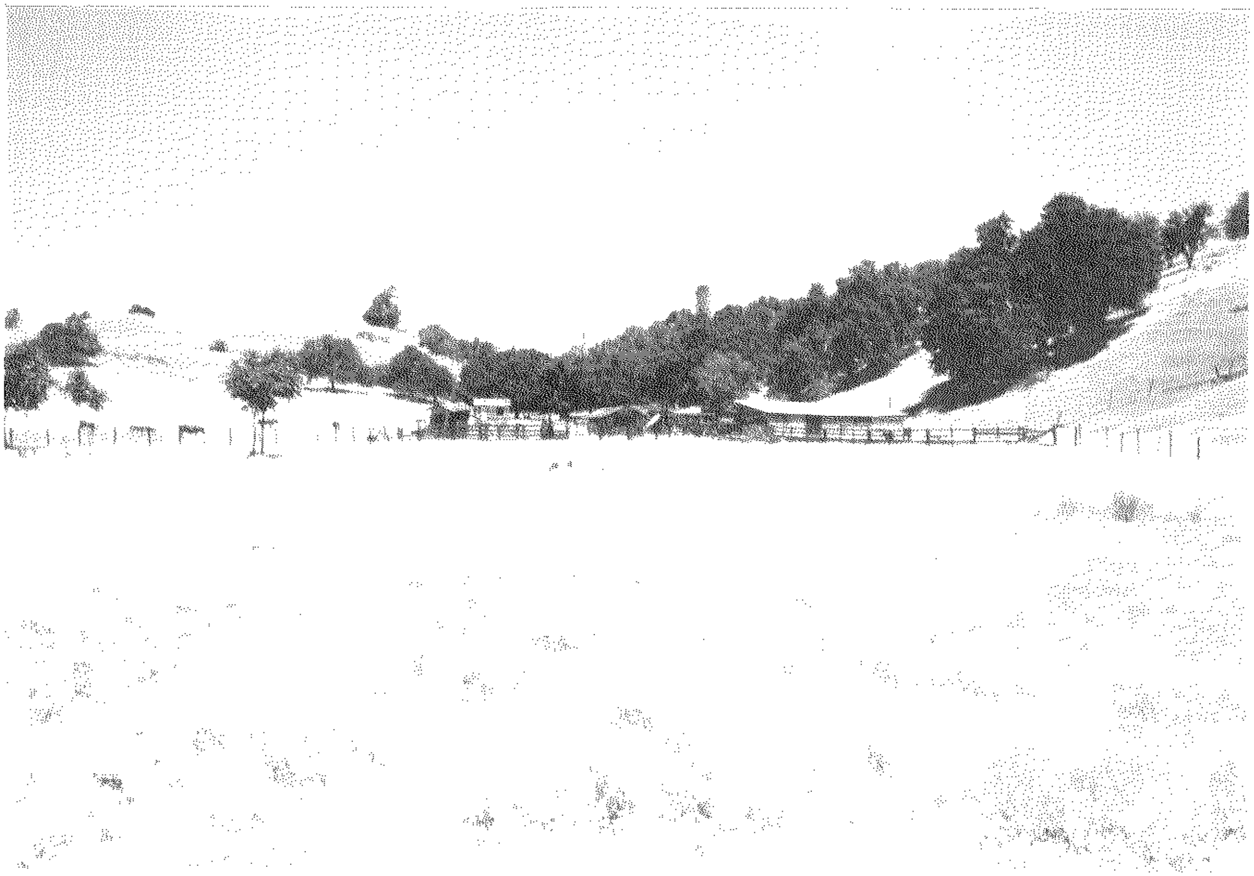


Figure 3-1. Owens Pasture Looking Northwest Along Strike of Fault

case would have been washed down from the hills to the north. Such a zone was found in the North Trench at the location shown roughly in Fig. 3-2, although evidence for its precise location was not as strong as had been hoped. Virtually no evidence was found in the South Trench. In order to define the strike as shown in Fig. 3-2, geological evidence in the swale and further to the southeast was considered, as was the location of the creepmeter and the records obtained from it. Based on these considerations, which include subjective judgments, the strike is assumed to be as shown in Fig. 3-2. This important decision directly affects the success of the project because it is essential that surface rupture intersect the pipelines.

3.2 Pipeline Segments

The Newmark-Hall [7] and Kennedy-Chow-Williamson [8] design models specify that the pipeline should be put into tension by fault offset. Accordingly, a pipeline segment has been constructed and instrumented which will be put in tension if the fault strand that runs through Owens Pasture is right lateral strike slip as is the case for the San Andreas Fault as a whole. As indicated in Fig. 3-3, one segment, designated T (for Tension), is oriented at 40° to the fault strike. It is instrumented with strain gages on the spring lines in order to measure extension and bending in a horizontal plane; since lateral fault movement is predicted to dominate, it is assumed that bending in a vertical plane will be negligible. The strain gages are concentrated near the assumed fault crossing in order to resolve the variation of interface friction as a function of distance from the crossing. This reflects a highly idealized view of pipe-soil interaction and of the fault as a single plane intercepting the pipe. The simple picture is consistent with the design methods the experiment is intended to evaluate; the physical situation is certain to be more complicated. A comparison segment, designated C (for compression), is oriented at -40° to the fault strike and will be subjected to compression.

3.3 Construction

Two welded steel pipeline segments have been built, instrumented and buried. In Fig. 3-3, Segment C is oriented SW-NE at -40° with respect to the strike of the fault. Segment T is oriented SE-NW at +40° to the fault strike. The pipe, manufactured by

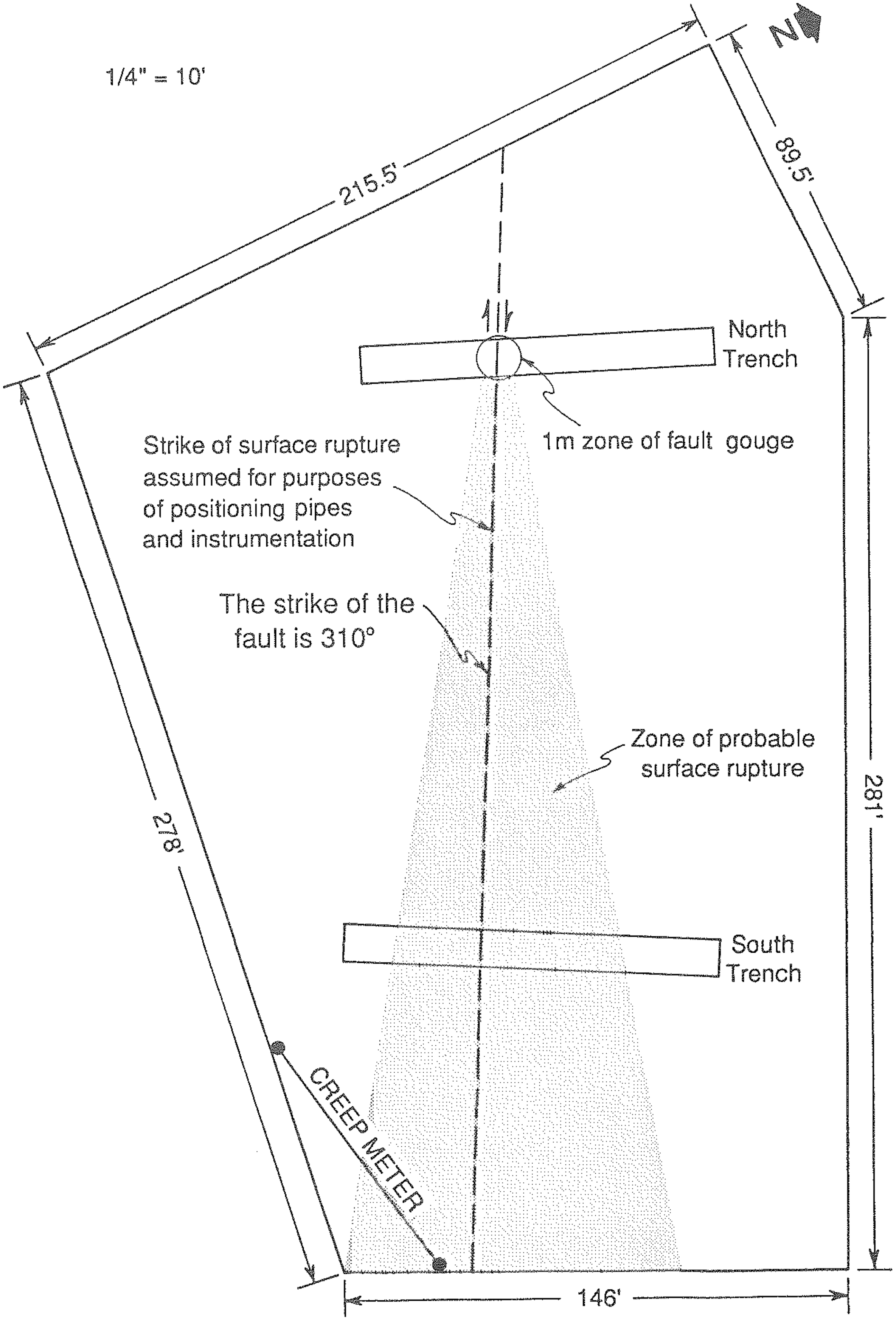


Figure 3-2. Assumed Zone of Surface Rupture, Owens Pasture

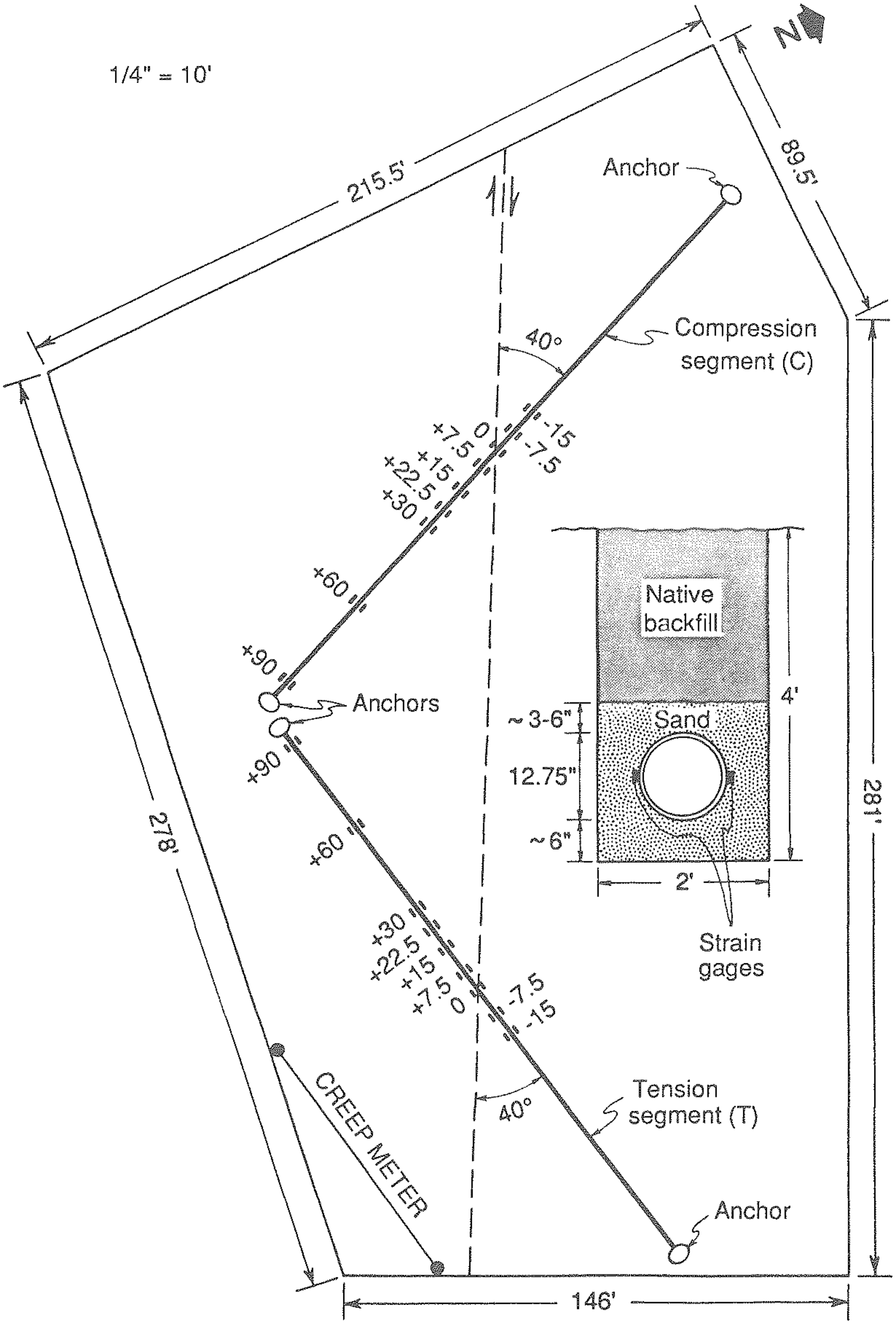


Figure 3-3. Orientation and Strain Gage Locations, Welded Steel Pipe Segments

Northwest Pipe & Casing Company, is designated as 12 3/4" o.d., 12 gage, bare steel pipe with weld bell ends. No specifications are available from the manufacturer; the steel will be tested under the project in the future. For planning purposes, it is assumed that the pipe is a mild steel resembling ASTM A500-72 and that it has a yield stress of 33,000 psi. The pipe was delivered in 40 ft lengths and welded at the site. It is standard practice for pipe of this type to be supplied with one end flared so that the butt end of the adjoining segment can be inserted about one inch. This permits using a fillet weld, which is much easier and more reliable to make under field conditions than a butt weld. Segment C is nominally 200 ft long, and hence contains four welds. Owing to size and shape of the pasture, segment T is 194 ft long and also contains four welds. A disc two feet in diameter is welded to the ends of each pipeline in order to restrain axial displacement. At the time of final backfilling, the ends will be encased in concrete also to resist movement (Fig. 3-4).

The welded steel pipe was laid in a two foot wide trench excavated to a depth of at least four feet. Then, a six inch layer of river sand was poured in the bottom of the trench to provide a bed and the pipe was then rolled into the trench. The trench was widened to four feet at locations where strain gages are attached in order to provide room for the installers to work; (Fig. 3-5). After welding the strain gages, attaching the leads and stringing cables, the trenches were backfilled with river sand up to three to six inches above the level of the crown. Then native spoil from the trench excavation was replaced and compacted by driving the tractor-backhoe over it. The cables were gathered at the apex of the triangle formed by the pipe segments and fault strike and protected. They will remain there until the Data Acquisition System is purchased under the second year of the grant.

Eight ductile iron pipeline segments were emplaced in two foot wide trenches. Each segment is comprised of two or three 18 foot pipe lengths oriented at 60° and 30° with respect 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. Pipe segments oriented at 30° to the fault strike are expected to undergo four inches x (Cos 30°) and some rotation; segments oriented at 60° to the strike are expected to undergo

a) Compression Segment, Looking South Southeast; Shows Flange Anchor

b) Tension Segment, Looking West Southwest

Figure 3-4. Welded Steel Pipeline Segments

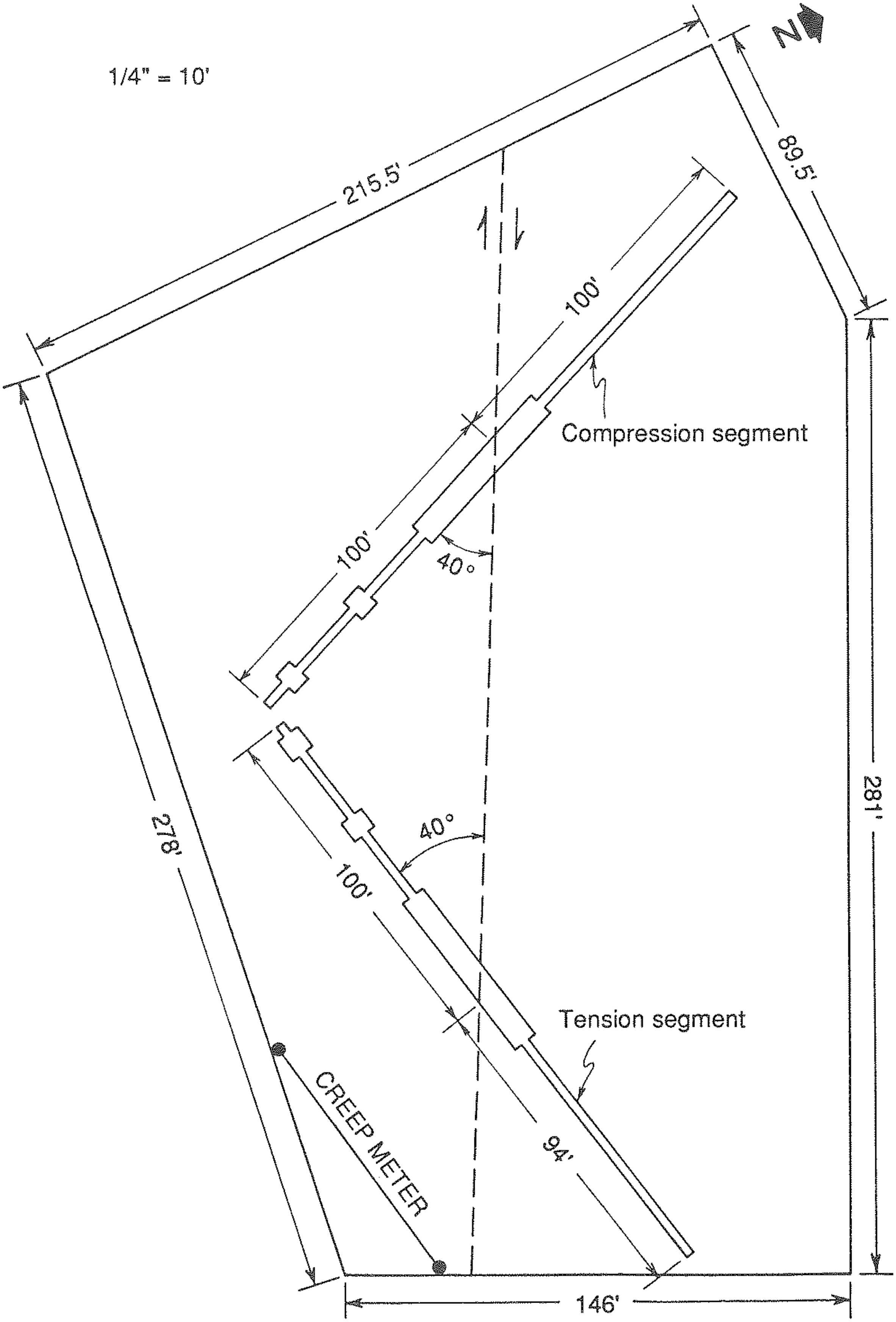


Figure 3-5. Trenches for Welded Steel Segments

four inches x (Cos 60°) and larger rotation than companions oriented at 30° (Fig. 3-6, 3-7). As in the case of the welded steel segments, the trenches were widened for access at points where transducers are installed. The laying condition is similar to that for the welded steel pipe in that the trenches are four feet deep with a six inch layer of sand backfill. Individual pipe lengths were put in the trench and joints were formed under supervision of representatives of US Pipe and Foundry Co. which donated the pipe and fittings. The pipes with restrained joints were filled with water and pressurized to 100 psi to seat the seals. The pipes with unrestrained joints cannot be pressurized until the ends are anchored and backfill completed. Backfill will be completed with sand up to the crown of the pipes followed by native spoil from the trench excavations. As in the case of the welded steel pipe segments, the ends of the ductile iron segments are restrained by encasing them in concrete anchors. The purpose of this is to prevent joints from opening under water pressure as well as to force deformation to occur at the joints.

3.4 Instrumentation

The welded steel pipes are instrumented with weldable strain gages. The bridge circuit is described in Appendix A. A one-quarter bridge is used, making each gage self compensating for temperature changes. At burial depth of three and one-half to four feet, temperature fluctuations are probably negligible; however, we plan to attach a thermocouple to a short length of pipe at the same depth and with the same laying condition to confirm this assumption.

The ductile iron pipes are instrumented with displacement transducers. Operations of the transducers is described in Appendix A. As shown in Fig. 3-8, each joint has one transducer designed to measure extension and another attached to an arm that measures rotation. A typical transducer assembly was constructed by Torque and Tension Systems in their laboratory and calibrated for combinations of rotation and extension. Results of the calibration tests will be reported later. Each assembly is encased in a smooth shroud which is intended to keep out soil. Waterproofing is done inside each transducer.

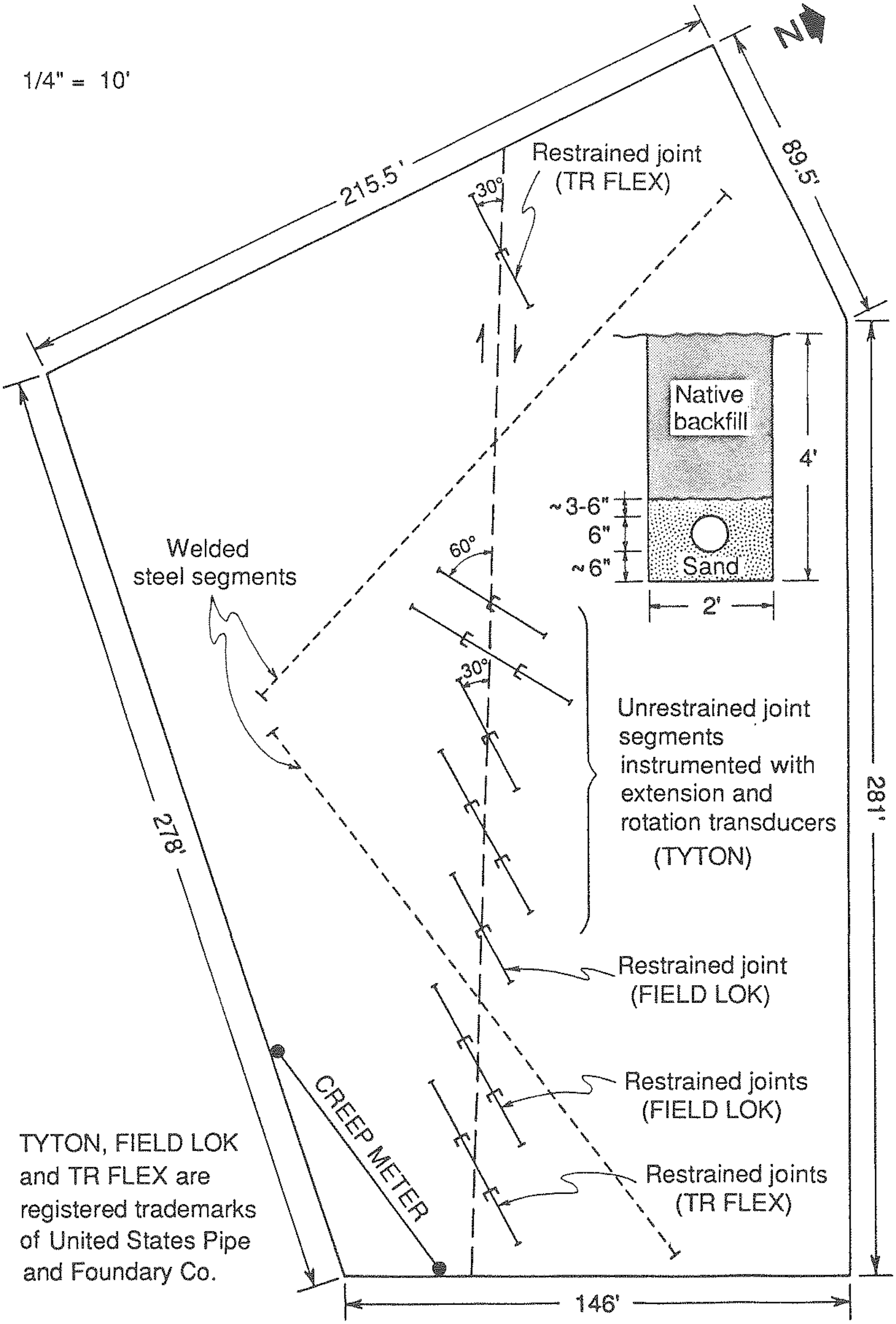


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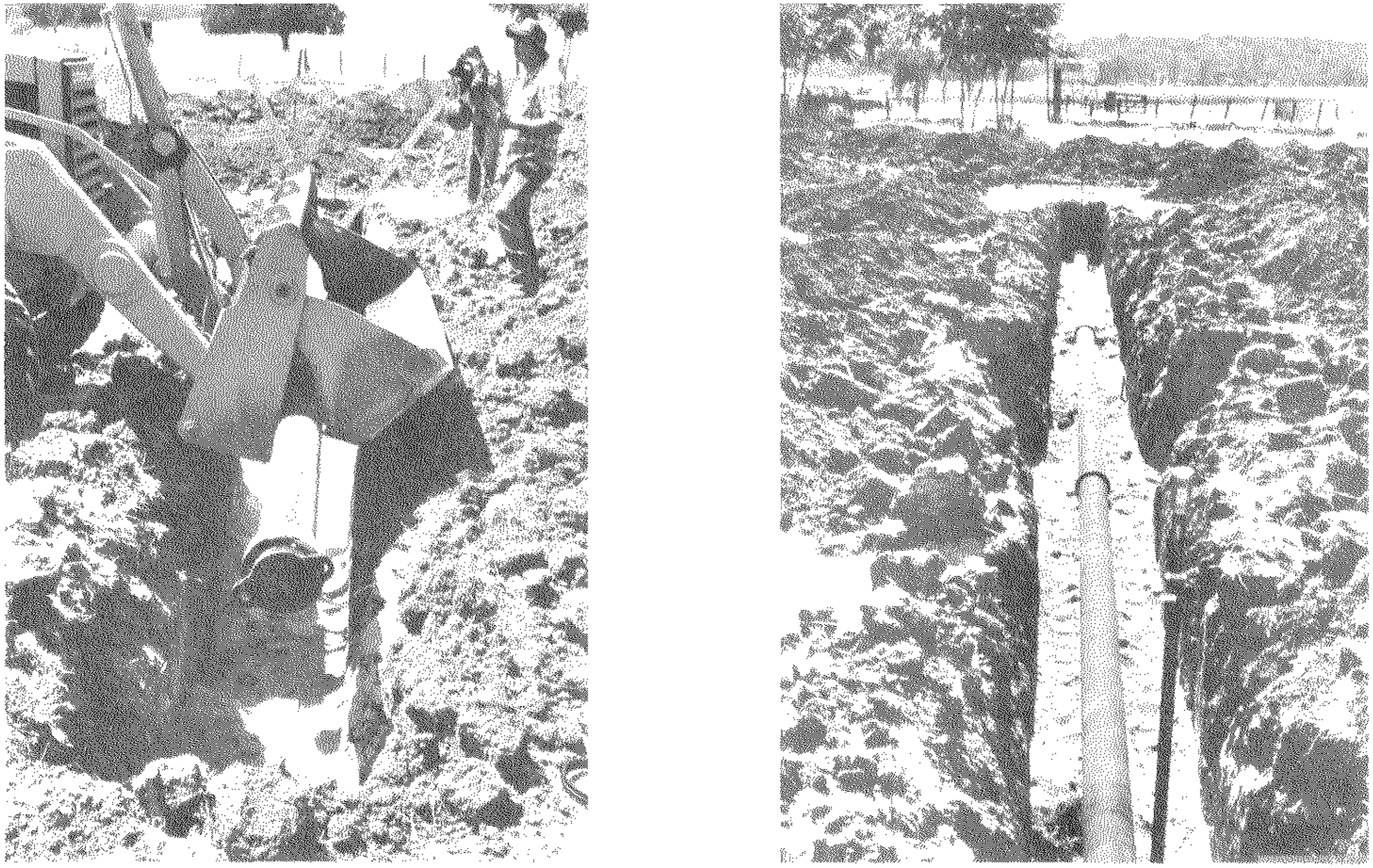
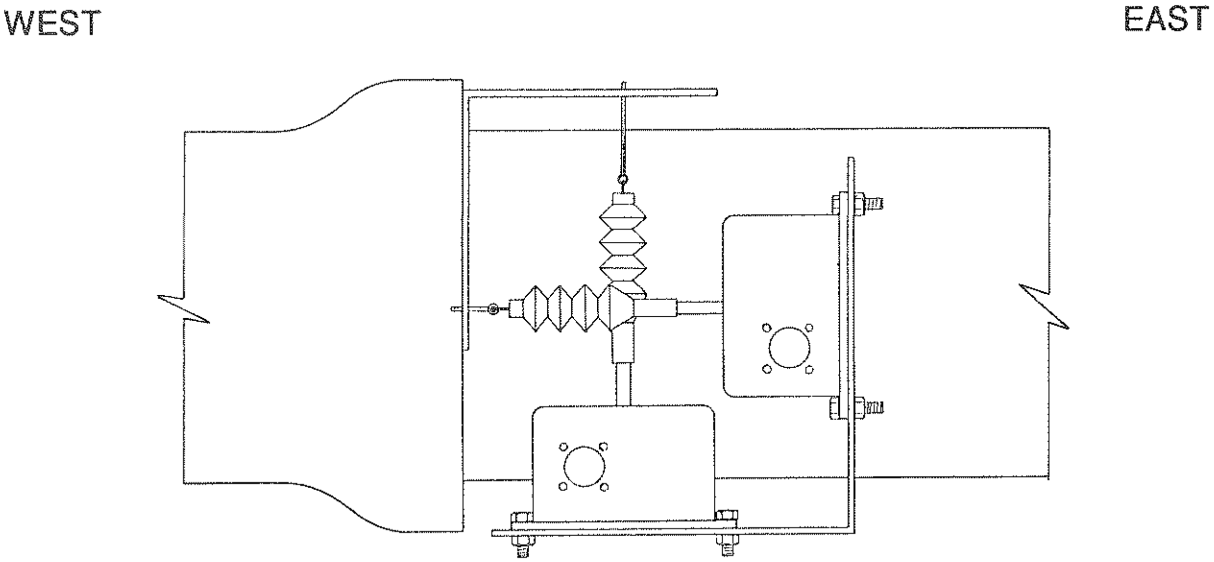
Figure 3-6. Orientation and Joint Types for Iron Pipe Segments



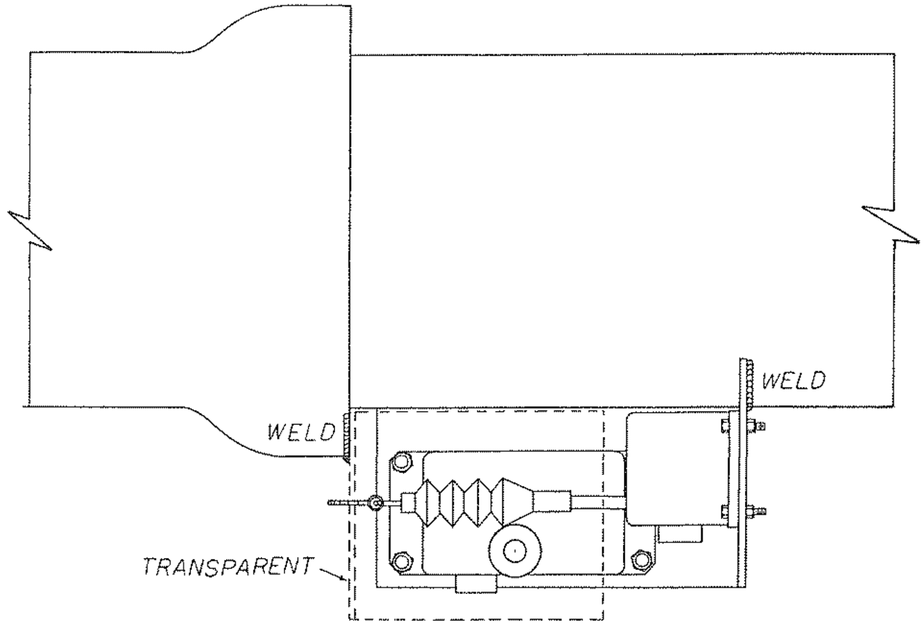
a) Laying Ductile Iron Pipe Segment

b) After Laying, Before Instrumenting 3-Segment Pipeline; Unrestrained Joints

Figure 3-7. Ductile Iron Pipe Segments



a. Plan



b. Elevation (looking North)

Figure 3-8. Rotation - Extension Transducers

SECTION 4
SUMMARY AND OBSERVATIONS

Progress in constructing and instrumenting pipeline segments has been satisfactory. After negotiating unsuccessfully with three other property owners, a lease permitting use of Owens Pasture was signed on July 10, 1987. Within thirty days following signing the lease, the steel pipelines were in the ground with instrumentation. Within another thirty days, the ductile iron pipes and instrumentation were also in place. This accelerated schedule is required in order to have all trenches closed before heavy rains begin; the rainy season in Central California begins about November 1. Also, the window of maximum likelihood for recurrence of the 1966 Parkfield-Cholame earthquakes is January 1988 so that rapid progress is essential to have the experiment, including data acquisition system, in place.

The Owens Pasture site is flat and accessible to heavy equipment. It has an adequate exposure for solar generation of power. There was surface expression in the Pasture showing lateral offset during the 1966 Parkfield-Cholame earthquakes. The USGS creepmeter strongly indicates that there is near-surface expression of fault movement in the Pasture. These factors support the choice of site. Arguing against the site is the fact that subsurface evidence of historical fault movement is slim, making it difficult to choose the best location for short pipe segments, such as the ductile iron pipes. Also, after a heavy rain, water stands in the Pasture for several days indicating that the subsurface soil is saturated, which affects the pipe-soil interface friction. Since the fault gouge zone tends to act as a barrier to water it is likely that the northeast side of the fault is wetter than the southwest side, at least with regard to run-off from the hills. The presence of water increases the likelihood of losing channels of instrumentation over a period of several years.

The experiment would benefit from having local strong motion records. However, the nearest strong motion accelerometers are in Parkfield, about two km to the east. No instruments of this kind are included in the budget for the project. Alternatives are currently being explored, including inviting Japanese researchers to participate in the project and bring their own accelerometers.

SECTION 5
REFERENCES

1. Brown, R.D. et al, "The Parkfield - Cholame California Earthquakes of June-August 1966 - Surface Geologic Effects, Water Resources Aspects and Preliminary Seismic Data," U.S. Geological Survey Professional Paper 579, U.S. Government Printing Office, 1967.

2. _________ "A Proposed Initiative for Capitalizing on the Parkfield, California Earthquake Prediction," Board of Earth Sciences, Commission on Physical Sciences, Mathematics and Resources, National Research Council. National Academy Press. Washington D.C., 1986.

3. Shinozuka, M. and T. Koike, "Estimation of Structural Strains in Underground Lifeline Pipes," Proceedings of the Lifeline Earthquake Engineering Symposium at the 3rd U.S. National Congress on Pressure Vessels and Piping, San Francisco, California, June 25-29, 1979, ASME, pp. 31-48.

4. Shinozuka, M. and T. Koike, "Seismic Risk of Underground Lifeline Systems Resulting from Fault Movement," Proceedings of the 2nd U.S. National Conference on Earthquake Engineering, Stanford University, Stanford, California, August 22-24, 1979, pp. 663-672.

5. O'Rourke, T.D., M.D. Gregoriu and M. M. Khater, "Seismic Response of Buried Pipelines. A State of the Art Review," Decade of Progress in Pressure Vessel Technology-1985, C. Sundararajan, Chief Editor, ASME, NY, NY.

6. Committee on Water and Sewage Lifelines, ASCE Technical Council on Lifeline Earthquake Engineers, "Advisory Notes on Lifeline Earthquake Engineering, Section IV, Water and Sewage Lifelines," ASCE, 1983.

7. Newmark, N.M. and W.J. Hall, "Pipeline Design to Resist Large Fault Displacement," Proc. U.S. National Conference on Earthquake Engineers, June 18-20, 1975, Ann Arbor, Michigan.

REFERENCES (concluded)

8. Kennedy, R.P., A.W. Chow, and R.A. Williamson, "Fault Movement Effects on Buried Oil Pipelines," Journal of the Transportation Engineering Division, Proceedings of ASCE, Vol. 103, 1977.

9. O'Rourke, T.D. and C.H. Trautmann, "Earthquake Ground Rupture Effects on Jointed Pipe," Lifeline Earthquake Engineering, The Current State of Knowledge, 1981, D.C. Smith, Ed., ASCE, 1981, pp. 65-80.

10. Bakun, W.H. and A.G. Lindh, "The Parkfield, California, Earthquake Prediction Experiment," Science 229, 1985, pp. 619-624

APPENDIX A

A.1 Instrumentation Strain Measurement Welded Steel Pipe

Welded steel pipe is instrumented at the springlines with weldable strain gages. Each is recorded on a dedicated instrumentation channel. No compensation gages are used. Strain is measured using the Wheatstone bridge circuit (Fig. A-1). This circuit consists of four resistive elements, one of which is the strain gage installed on the pipe. The additional three resistors to complete the bridge are added prior to the circuit connection to the CDAS.

The resistive Wheatstone bridge will be electrically balanced at time of installation by use of the amplifier and circuitry in the CDAS. The voltage offset (unbalance), which is proportional to the resistive unbalance of the bridge, will be recorded. The CDAS will begin recording using the initial readings as zero strain. Any movement of the earth which applies strain will be recorded as strain on the CDAS.

A bridge completion network will be used for resistive conditioning of the strain gage system prior to connection to the CDAS. This consists of connecting the associated 3 precision resistors to the strain gage. The precision resistors will not change resistance (within the tolerance of the element, .01%) and any unbalance of the bridge will be considered the influence of the strain gage mounted on the pipe.

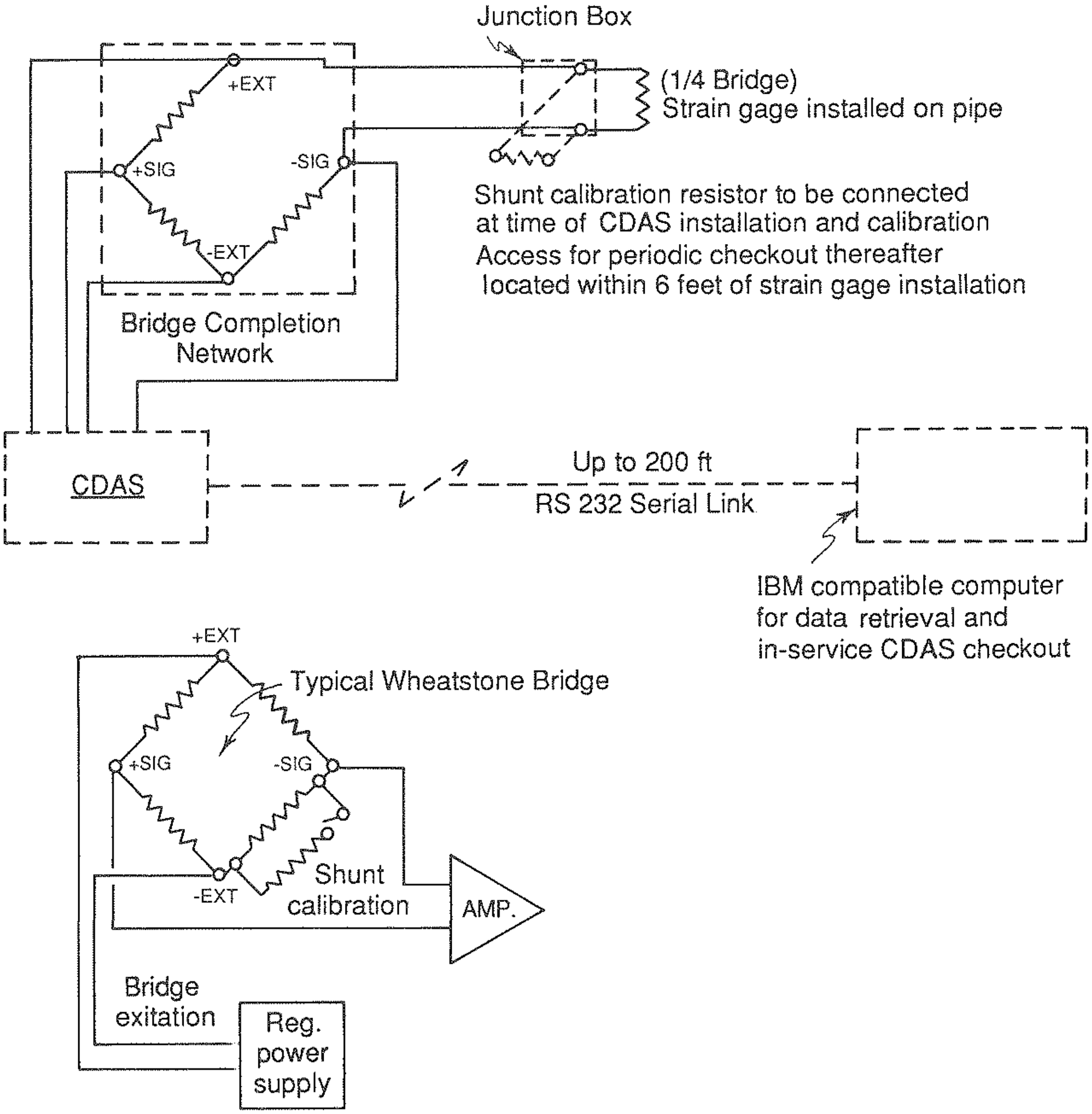


Figure A-1. **Wheatstone Bridge Used to Measure Strains on Welded Steel Pipe**

A.2 Displacement, Rotation Measurement at Flexible Joints in Ductile Iron Pipe

Displacement transducers are mounted on brackets as shown in Fig. 3-8 to measure extension and rotation. The relative position is measured by mounting the transducer to the base bracket and attaching the cable to the other. In the event of an earthquake, the pipe joints will extend and possibly rotate. The two brackets attached to the pipe will also move relative to each other. The movement will pull the cable out of the transducer. This action causes a voltage change proportional to the extension of the cable. The extension of the cable rotates a spring loaded shaft coupled to the sensing circuit of the transducer. The constant force spring provides torque for cable retraction and maintenance of tension on the cable.

The output of the transducer appears to the CDAS as a full bridge Wheatstone bridge. Cross-axis sensitivity (change in apparent rotation due to pure axial deformation at the joint; change in apparent axial deformation due to pure rotation) will be accounted for by calibrating the transducer outputs in the laboratory for various combinations of rotation and extension.

A.3 Central Data Acquisition System (CDAS)

The CDAS is a microprocessor based instrument which will monitor up to 56 channels of strain and displacement information. The system contains the necessary circuitry to provide the Wheatstone bridge excitation and accept the low level signals from the strain gages. The CDAS processor module contains a DC to DC converter and voltage regulators to provide regulated power for analog and digital functions from the unregulated 12 VDC battery. The precision analog interface module contains a 16 bit A/D-D/A converter, a precision voltage reference, a gain switchable differential amplifier, an integrator, and a precision resistive voltage divider for self calibration. The analog input module provides the capability of accepting the 56 channels of inputs and contains transient protection circuitry and RF filtering.

The CDAS system will take the data by exception, independent of time. This technique assures that the data of interest is recorded without the dependence of a time function. It will have 6 data inputs from selected channels to act as triggers. When any of the 6 channels reaches the preprogrammed data entry level (threshold), the system will scan ALL channels and record for a total of 1 minute and shut down. There is provision to store data for up to 15 1-minute events. If there is a residual strain or displacement associated with the activity described above, the instrument will assign a new zero to the 6 trigger channels and the system will wait for a new event to trigger the system again. This function will continue for a total of 15 events at which time the storage module will be full and the system will require a site visit from project personnel to empty the on-site data into an IBM PC or compatible computer. After the data has been retrieved from the CDAS, all functions will be reset to zero and an additional 15 minutes of 1-minute events can be recorded.

The CDAS package includes operational software to interface with an IBM compatible computer for data extraction and manipulation. The data from the CDAS can be transferred into a computer up to 200 ft away from the on-site protective structure.

APPENDIX B

Notation

L_a	effective anchor length
d_f	lateral offset imposed on pipeline
β_f	angle of fault strike with respect to pipe axis
D	diameter
γ	unit weight of soil backfill
K_o	coefficient of laterial soil pressure
H	depth to center of pipe
σ_1, ε_1	stress, strain at idealized yield point in steel pipe
σ_2, ε_2	stress, strain in hardening regime
E_1, E_2	Young's modulus, hardening modulus

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