

ESTIMATION OF MAXIMUM SURFACE DISPLACEMENT OF THE ELDORADO VALLEY FAULT, CLARK COUNTY, NEVADA, FOR PIPELINE DESIGN

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ABSTRACT: The focus of this study has been to investigate the Eldorado Valley fault and to determine the potential fault hazard to a proposed natural gas pipeline crossing the fault. The proposed 24-inch pipeline will begin at a point approximately 6.5 miles south of Henderson, Nevada and will extend southward across Eldorado Valley towards Searchlight, Nevada. From a preliminary study of the proposed alignment, a relatively well-defined fault scarp offsetting recent alluvial deposits was observed on the northeast margins of Eldorado Valley. This two mile long escarpment along the base of the McCullough Range was found to trend towards the pipeline route approximately 3 miles to the southwest.

Use of morphologic dating techniques has shown the most recent movement of the Eldorado Valley fault scarp to be less than 11,000 years old. Diffusion-equation modeling of the scarp profiles suggest that the age of the fault lies between 5,500 and 8,200 years before the present. Based on this, the fault was regarded as "active" and therefore, for design purposes, expected to have displacements within the lifetime of the proposed project.

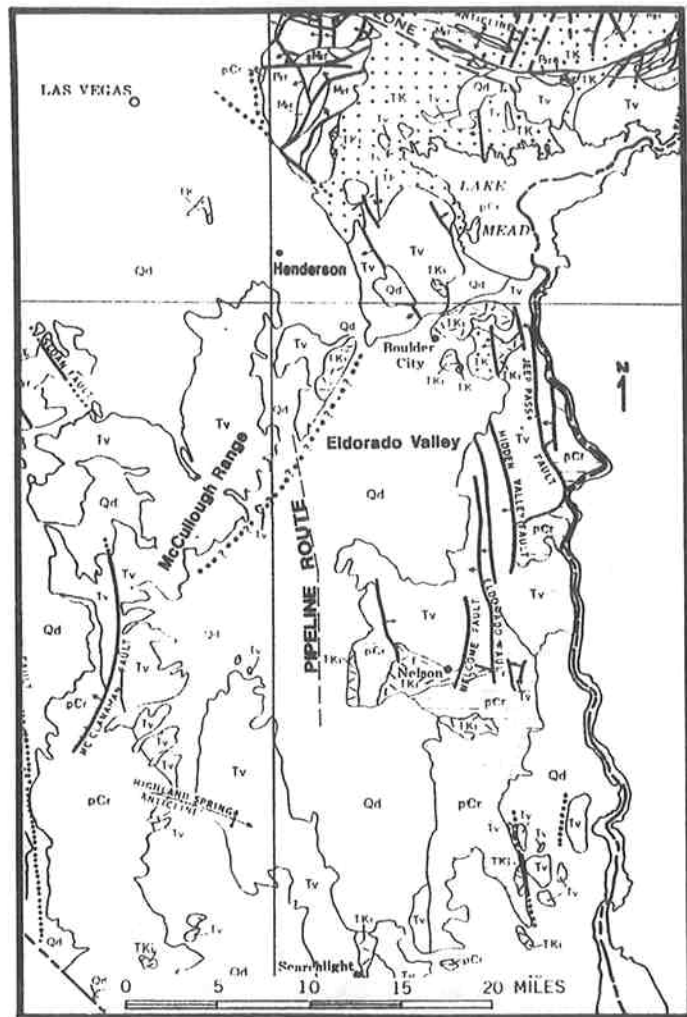
Ground rupture along a fault poses the greatest potential hazard to an underground pipeline crossing a fault. Based on field observations of measurable past surface displacements and comparison with statistical models which relate fault rupture length with surface displacement, we have formulated an estimate for the potential maximum surface displacement for the Eldorado Valley fault. A maximum surface displacement of 7.1 feet was derived from empirical relations following recognition of possible fault segments. In contrast, a maximum displacement of 23.1 feet was determined from the measurement of existing scarp heights. The latter value is believed to be greatly overestimated since the normal fault scarp is suspected to be composite or the result of multiple events.

The following paper outlines methods which have been used to investigate the potential hazards and provide design considerations for the pipeline across the fault. Restrictions imposed by the Threatened Species designation of the Mojave Desert Tortoise limited our approach. Field programs other than the surficial studies employed required lengthy application periods beyond the time constraints of the project. Therefore, field trenching to verify our reported estimates could not be performed.

INTRODUCTION

The proposed construction project consisted of 19.2 miles of 24-inch natural gas pipeline located in Clark County, Nevada, approximately 20 miles south of the City of Las Vegas at its nearest point. The pipeline route crosses Eldorado Valley beginning at a point approximately 6.5 miles south of Henderson, Nevada and extending southward towards Searchlight, Nevada. During an initial environmental analysis statement prepared for the proposed pipeline alignment, we identified a possible fault hazard for a portion of the pipeline route in the southeast quarter of Section 6, Township 24 South, Range 63 East. This location along the alignment is near its north end and on the northern margins of Eldorado Valley where the proposed pipeline leaves the McCullough Range (Figure 1).

Figure 1. Location of study area south of Las Vegas, Nevada showing proposed pipeline route and fault crossing. (Adapted from Longwell and others, 1965.)



From the initial study of the route, a relatively well-defined fault scarp offsetting geologically recent alluvial deposits was observed on the southeast margins of the McCullough Range, 3 miles northeast of the proposed alignment. The escarpment extends over a 2-mile length along the base of the range front and trends toward the pipeline route to the southwest. Between the southwestern end of this surficial feature and the pipeline alignment, the fault is poorly delineated and is only evident through secondary features. There is no obvious evidence for the fault west of the pipeline route. This fault occurrence has been previously identified including Longwell and others, 1965 (Fig. 1) and Anderson, 1977.

PURPOSE

Faults are not only important because they are sources of energy for earthquakes but because of the hazard of ground-surface displacements along them. Ground rupture along a fault poses the greatest potential hazard to a pipeline structure crossing the fault. Our work was implemented in an effort to determine level or degree of fault activity and to predict potential movement along the fault for pipeline design considerations. To do this, the study was divided into three phases as follows:

Phase 1. Relative Age Dating of the Last Fault Displacement.

Faults that can be expected to have displacements within the lifetime of a structure or engineering project have been termed "active faults." Therefore, faults with surface displacements occurring within Holocene time (about the last 11,000 years) have been considered active for design and planning purposes.

Phase 2. Estimation of Maximum Surface Displacement.

A maximum surface displacement is defined as the largest displacement along an active fault likely to occur over a given time interval such as the lifetime of an engineering structure. For design purposes, the maximum expected surface displacement along a fault rupture should be used unless there is strong evidence to support lesser displacements at the project location.

Phase 3. Determination of Fault Crossing Location and Angle with Respect to the Pipeline.

Knowing the location of the fault crossing and expected displacement components is important for implementing design mitigation measures for the pipeline at the intersection of the fault zone with the potential for future surface rupturing. (This last phase has not been performed at the time of this writing).

GEOLOGIC AND GEOMORPHIC SETTING

The Eldorado Valley is an intermountain basin which is geomorphically characteristic of the Basin and Range Province of the Western United States. Tectonic movement along northerly trending fault blocks, principally during the late Mesozoic and Tertiary time, led to relative uplift of the hill and mountain regions and subsidence of the valley basin. The subsiding valley floor has provided a natural trap for alluvial sediments washed down from the surrounding uplifted terrains resulting in thick accumulation of alluvial deposits. The study site lies along the southeast margins of the northern extension of the McCullough Range. These uplifted mountains are generally comprised of Tertiary volcanic and intrusive rocks.

As indicated, a fault zone which has dissected recent alluvial deposits lies at the base of the McCullough Range along the margins of Eldorado Valley to the southeast. This fault zone is expressed by a series of linear escarpments in the alluvium that trend northeast-southwest along the base of the mountain front (Figure 2). The feature is generally believed to be a high angle, normal fault characteristic of Basin and Range-type faulting.



Figure 2. Fault scarp approximately 4 miles northeast of pipeline route.

The trace of the fault zone can be seen as nearly continuous scarp segments along its exposed length of about 2 miles. The most prominent of the southeastern facing escarpments are located on the southwestern end of the scarp trace which rise up to heights of 25 feet. A smaller fault scarp is found a couple hundred feet up slope of the larger scarp along most of its extent. This secondary scarp is estimated to be 2 to 4 feet in height. Other fault related features include a small graben or down-dropped block observed along a portion of the larger scarp at its base.

The existing fault scarps become obscured approximately 3 miles from the pipeline route. The fault-controlled, uplifted range front continues towards the southwest, reducing in topographic relief until about 1/2 mile northeast of the pipeline alignment. The fault is not evident where it crosses the alluvial fan along the proposed pipeline right-of-way. However, there is secondary evidence including range front geomorphology that the fault zone extends to the southwest of the pipeline route.

The study area consists of undeveloped desert. Vegetation observed throughout the locale consists of sparse creosote bushes. The surface deposits on the fault scarp slopes generally range from sand to large boulders. There is minor calcium carbonate cementation within the soil. On many scarp surfaces, cobbles or boulders are residually concentrated since fine material has been removed, leaving more stable armored slopes.

RELATIVE AGE DATING

As previously discussed, the relative age of the tectonic fault located on site is important in assessing the potential hazard of the fault to the proposed project. Several morphologic techniques of relative age-dating of the fault scarp were employed for this study. These techniques are dependent upon the rate of fault scarp degradation following ground rupture. In simple terms, scarps having the same degree of degradation will be of the same age under similar conditions. Based on this, a fault scarp with an unknown age can be relatively dated to a scarp having a known age determined by other procedures and in an environment similar to that being studied (Wallace, 1977). In some cases it may be the only dating method that can be used for faults, especially in the Basin and Range Province. In our opinion, morphologic dating of the Eldorado Valley fault scarp was the only method that could be employed with any degree of accuracy at this time.

Field Investigations - Scarp Profiling

Field investigations for this study consisted of measuring the existing profiles along the fault scarp for the morphologic age estimation methods. Since coarse materials comprise many of the scarps, profiles were measured with an extendable 25 foot long fiberglass rod and survey level. The survey level was placed at the inflection point between the crest of the scarp and the upper alluvial fan surface. The major scarp inflection points were visually determined and the relative elevations of each were measured. Slope distances between these chosen points were measured afterwards. A total of 25 scarp profiles were measured in this manner. However, not all profiles were used in the following morphologic dating techniques especially those scarps considered armored with coarser material (appear less degraded with higher slope angles).

Morphologic Dating - Empirical Methods

Observed correlations between scarp height, slope, and age have resulted in the development of semi-quantitative methods for estimating fault-scarp age, and hence a method by which prehistoric earthquakes might be dated. The principle studies developing strictly empirical methods of morphologic dating have been by Wallace (1977), Bucknam and Anderson (1979), and Nash (1980).

Wallace (1977)

This method was first suggested by Robert E. Wallace (1977). He observed that a fault scarp, once it has formed, immediately begins to change through the processes of degradation. The slope of the scarp lessens with age through this degradation. From measuring slope angles of scarps in the Basin and Range with relatively known age-dates (this includes dateable ancient glacial lake shoreline scarps that degrade in a similar fashion), Wallace put together a simple relationship between the age of a scarp with present slope angle.

Using this simple method by Wallace the age of the Eldorado Valley fault scarp from our field observations would place it on the order of between 5,000 to 10,000 years old. However, Wallace recognized several limitations to this simple approach since the degradation of a fault and the corresponding slope angle are affected by many variables. Scarp-slope angle is greatly dependent on scarp height for scarps of a given age.

Buckman and Anderson (1979)

Buckman and Anderson (1979) presented refinement on this approach. By comparing slope angles with estimated age for scarps of a given height, they developed a more quantitative method of determining the age of scarps. The procedure provides a means of ranking scarps according to relative geomorphic age within a general age framework by comparing plots of similar data from other faults with known ages.

We have compared the data obtained from the Eldorado Valley fault scarp with respective data from four scarps of relatively known ages. The ages of these comparison scarps have been refined and updated (compiled from the literature) since the work by Bucknam and Anderson in 1979. The average of the data from the scarp on site falls between scarps dated at 9,000 (Drum Mts.) to 14,500 years old (Lake Bonneville shoreline).

Morphologic Dating - Mathematical Modeling Methods

Another approach to morphologic dating of scarps comes from model calculations derived from diffusion equation mathematics. With either analytical or computational techniques, one may compute elevation profiles to match some particular scarp profile or functional relationship between scarp steepness and scarp height. This more quantitative approach has been developed by Nash (1980), Hanks, et al. (1984), Hanks and Andrews (1987, 1989) and several others.

Hanks, et al.(1984)

We have employed the finite slope, initial value scarp with the linear diffusion model from Hanks, et al. (1984) to the Eldorado Valley fault scarp. In addition, the effect of the far-field slope has been accounted for in this study as discussed by Hanks and Andrews (1989).

Basically, using computational techniques, we have compared the relationship between the scarp height (offset) and the reduced scarp slope of the Eldorado Valley fault scarp to models of the same functional relationship as dependent on age. To accommodate this method, we disregarded the profile data obtained from our field investigation which fell outside the constraints of the model. Additionally, we assumed some parameters in the model such as the natural angle of repose for the scarp materials at the site (35 degrees) and that the value of diffusivity for the Basin and Range is constant ($1.1 \text{ m}^2/1000 \text{ years}$) and applies at the site.

Figure 3 shows the results of the comparison to each modeled relationship with age. The Eldorado Valley data appears to fall between the modeled curves for $kt=6$ (5,500 yrs.) and $kt=9$ (8,200 yrs.). Given the value of diffusivity of 1.1, the age of Eldorado Valley fault scarp lies between 5,500 and 8,200 years before the present.