Assessment of the Design Displacement Values at Seismic Fault Crossings and of Their Excess Probability

STROM Alexander1*, IVASCHENKO Alexey2, KOZHURIN Andrey3

1 Institute of Geospheres Dynamics of Russian Academy of Sciences, Moscow, Russia
2 Institute of Oceanology of Russian Academy of Sciences, Moscow, Russia
3 Geological Institute of Russian Academy of Sciences, Moscow, Russia

*Corresponding author, e-mail: a.strom@g23.relcom.ru

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Abstract: Line structures such as pipelines that cross active faults should be designed to retain leak-tightness if the design displacement (D_{design}) occurs. Principal approaches to the D_{design} and rupture kinematics assessment are described. They are based on relationships between earthquake magnitude, rupture length and displacement, and on the detailed field data on a specific fault that crosses the pipeline route. Since the future offset at the crossing may exceed the design value, the probability of a displacement occurrence where the safety of the structure can not be ensured should be estimated. Assessment method on such event probability is described and exemplified through active fault studies carried out at several pipeline projects in Russia.

Keywords: Active Fault; Surface Rupture; Design Displacement; Pipeline; Sakhalin Island

Introduction

Large line structures such as pipelines, tunnels and canals often cross active faults that may rupture during earthquakes with single-event offsets up to several meters. It is important to ensure that these structures withstand the design displacement (D_{design}). The most critical are oil and natural gas pipelines, which, when ruptured, may cause significant economic loss and severe environmental pollution. Thus, special measures must be undertaken to guarantee the safety of pipelines where they cross active faults.

The main input parameters for pipeline/active fault crossing design are surface rupture location, sense of the displacement (fault kinematics) and single-event displacement values. Fault location and kinematics are determined on the basis of regional geodynamics analysis, and detailed geological-geomorphic mapping and trenching.

The D_{design} value assessment seems to be the most problematic issue. Generally, it can be estimated either on the basis of worldwide and/or regional relationships between earthquake magnitude, rupture length and displacement, or from the field data on the displacements typical of a fault in question. It can not be excluded, however, that during some surface rupturing event real offset may exceed the design value, so that the crossing design will not guarantee the pipeline leak-tightness. Thus, the problem that the probability assessment of 'rupturing' displacement may exceed the D_{design} Value arises.

These studies were carried out for the 800-km long oil and gas pipelines on Sakhalin Island that cross several active faults which could not be bypassed due to topographic and some other
limitations (normative distance from the settlements, main roads, etc.).

We should point out that only seismic faulting is analyzed hereafter. Slow continuous fault movements at rates ranging from millimeters to centimeters per year do not pose a significant threat to pipelines since they do not exceed periodic pipe movements caused by thermal or hydrodynamic deformations. Moreover, following the conservative approach, we consider any active fault pronounced in the topography as a result of rapid seismogenic displacement. It is obvious that a crossing construction that can withstand large single-event offset will also be able to sustain slow long-term deformations with cumulative value during structure lifetime (30-50 years) not exceeding the design single-event displacement value.

1 Assessment of Design Displacement Value

The design displacement assessment can be either probabilistic (Youngs et al. 2003), based on the global and/or regional relationships between earthquake magnitude and rupture length and fault displacement (Nowroozi 1985; Wells & Coppersmith 1994; Strom & Nikonov 1997, 2000; Chipizubov 1998; Matsuda 1998; Lunina 2001), or deterministic, based on field data on the displacements along the specific fault that crosses the pipeline route. The most detailed description of field methods of active fault study is presented in (McCalpin 1996, 2009).

The advantage of the probabilistic approach to the fault displacement hazard assessment – PFDHA (Youngs et al. 2003; Todorovska & Trifunac 2006) is its consistency with the commonly used probabilistic assessment of the peak ground acceleration (PGA) value. It allows estimating a wide range of displacement values along with the probabilities of exceedance (non-exceedance). Its practical usage, however, is limited, since in most cases no independent estimates of earthquake magnitudes that can be associated with an active fault in question are available. Commonly, earthquake magnitudes are derived just from the offsets of the past (historical or prehistoric) events. Thus, something like "vicious circle" appears – we calculate earthquake magnitude on the basis of the direct measurements of single-event displacements and then use this value to calculate the design displacement.

The additional uncertainty arises from the fact that it is generally not known whether the offset measured at a particular fault section or trenching site was maximal for that rupturing event, or average, or some other. Since most relationships of $M=f(D)$ have been derived from the data on maximal, or, rarely, average, displacements, this uncertainty reduces the accuracy of probabilistic $D_{design}$ estimates.

Similar, if not higher, ambiguity characterizes fault displacement estimates derived from the relationships between rupture length and maximal (average) displacement (Wells & Coppersmith 1994; Strom & Nikonov 1997), since the dimensions of a fault segment that can be ruptured in one event are rather hypothetical. Dating methods are not precise enough to distinguish individual faulting events in their succession, so a long-term cumulative surface rupture may be taken for a single-event feature. This can be exemplified by the North Anatolian fault (Barka 1992) or the faults bounding the Lut block in Iran (Nowroozi & Mohajer-Ashjai 1985). At the same time one could miss simultaneous formation of distant surface ruptures, such as those formed by some of the 1954 earthquakes in Nevada (Ryall & VanWormer 1980) or by the 1992 Suusamur earthquake in Kyrgyzstan (Ghose et al. 1997). In this case real fault length could be underestimated.

A method to estimate paleomagnitude and rupture extent from measurements of displacement at a single point on a fault was proposed recently by Biasi & Weldon (2006). It should be pointed out, however, that this study was based on the data on the San Andreas fault – one of the world-best studied active faults with distinct strike-slip kinematics. None of active faults that are crossed by the pipelines in question had been studied so extensively. In addition their kinematics are different. We think that additional studies are necessary to check if the approach proposed by Biasi & Weldon (2006) can be utilized in other cases, especially for active faults studied much less than the San Andreas fault.

It should be also noted that world-wide relationships between earthquake magnitude and