



ABSTRACT

Tunnels through fault fracture zones present unique challenges compared to usual tunnels, particularly in terms of seismic performance. The Bener Dam diversion tunnel, located in Indonesia, is one example of such a tunnel. However, no prior studies have been conducted to analyze the potentially complex seismic response of the tunnel. This study aims to investigate the tunnel's natural periods; to obtain appropriate ground motion records for the seismic analysis; to assess the effects of fault displacement, internal water pressure, and segmental joints; and to design a suitable tunnel lining that satisfies structural safety criteria.

The rock mass was characterized using the Geological Strength Index (GSI) system. Modal analysis was performed to determine the tunnel's natural periods. Ground motion records were selected and modified to reflect the site-specific and structural conditions. Non-linear time history analysis using Midas GTS NX was carried out to evaluate the tunnel's seismic response under various scenarios: with and without fault, with and without internal water, and using continuous versus segmental linings. The initial tunnel lining design was assessed based on structural failure safety and serviceability.

According to the GSI classification, the rock mass consisted of layers ranging from good to poor quality. Modal analysis found that the presence of the fault increased the tunnel's natural periods and altered its mode shapes. Eleven pairs of ground motions were selected and modified, with a peak ground acceleration of up to 0.44 g. The time history analysis results revealed that the wall segments resisted the highest fault shear displacements. The fault exhibited strike-slip behavior, causing significant differential movement. The effect of internal water pressure was insignificant, while segmental joint modeling reduced internal forces. Some segments in the initial design did not meet the safety criteria. Design adjustments were implemented to fulfill both structural and serviceability requirements, resulting in a safe final design.

Keywords: tunnels, earthquakes, faults, seismic performance, dynamic analysis.



ABSTRAK

Terowongan yang melewati zona retakan sesar menghadirkan tantangan tersendiri dibandingkan terowongan konvensional, khususnya terkait kinerja seismik. Terowongan pengelak Bendungan Bener di Indonesia merupakan salah satu contohnya. Namun, belum terdapat studi sebelumnya yang menganalisis potensi respons seismik kompleks dari terowongan tersebut. Penelitian ini bertujuan menyelidiki periode alami terowongan; memperoleh rekaman gempa yang sesuai untuk analisis seismik; mengevaluasi pengaruh pergeseran sesar, tekanan air internal, dan sambungan segmen; serta merancang lining terowongan yang memenuhi kriteria keamanan struktural.

Karakterisasi massa batuan dilakukan menggunakan sistem Geological Strength Index (GSI). Analisis modal digunakan untuk menentukan periode alami terowongan. Rekaman gempa dipilih dan dimodifikasi agar mencerminkan kondisi spesifik lokasi dan struktur. Analisis nonlinier riwayat waktu menggunakan Midas GTS NX dilakukan untuk mengevaluasi respons seismik dalam berbagai skenario: dengan dan tanpa sesar, dengan dan tanpa tekanan air internal, serta menggunakan lining kontinu dan segmental. Desain awal lining dievaluasi berdasarkan kriteria keamanan terhadap kegagalan struktural dan kelayakan layanan.

Berdasarkan klasifikasi GSI, massa batuan terdiri atas lapisan dengan kualitas bervariasi dari baik hingga buruk. Analisis modal menunjukkan bahwa keberadaan sesar meningkatkan periode alami dan mengubah bentuk mode getar. Sebelas pasang rekaman gempa dipilih dan dimodifikasi, dengan percepatan puncak tanah hingga 0,44 g. Hasil analisis riwayat waktu menunjukkan bahwa segmen dinding menahan pergeseran geser sesar tertinggi. Sesar menunjukkan perilaku strike-slip dengan perpindahan diferensial signifikan. Pengaruh tekanan air internal tidak signifikan, sementara sambungan segmental menurunkan gaya internal. Beberapa segmen pada desain awal tidak memenuhi kriteria keamanan. Penyesuaian desain dilakukan untuk memenuhi persyaratan struktural dan fungsional, menghasilkan desain akhir yang aman.

Kata Kunci: terowongan, gempa, sesar, performa seismik, analisis dinamik.