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Executive Summary Report

Rock Slope Design Criteria

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Problem

Most cut slopes in Ohio are designed by consultants hired by ODOT. Based on their experience and judgment, different consultants use different approaches for designing the cut slopes. They do not always take into account the geological and geotechnical characteristics unique to various areas of the state. This practice leads to inconsistent and, occasionally, poor slope design that can result in slope failures, creating hazards to traffic and causing damage to roadway structures. ODOT is interested in developing a comprehensive and consistent methodology for designing cut slopes that incorporates the geological and geotechnical characteristics of the rocks present in the state.

The majority of the cut slopes in Ohio consist of inter-layered sequences of competent and incompetent rock units of varying thicknesses. These slopes are highly susceptible to differential weathering and often result in undercutting-induced failures. Currently available methods of rock slope design can be used for slopes consisting of uniformly competent or uniformly incompetent rocks but cannot be applied to slopes consisting of inter-layered sequences of competent and incompetent rocks. Therefore, a comprehensive design approach, suitable for all types of geological scenarios, is needed.

Objectives

The main objective of this study was to develop a comprehensive, consistent methodology for designing cut slopes that takes into account the stratigraphic variations, engineering properties, and differential weathering of the flat-lying sedimentary rocks present in Ohio. The important aspects of design include selecting appropriate cut slope angles, bench locations, drainage methods, remedial measures, and catchment ditch dimensions.

Description

Twenty six representative cut slope sites along Ohio highways were selected for the study. Detailed field investigations were conducted to draw slope profiles, prepare stratigraphic cross-sections, map discontinuities, observe various modes of failure, and collect samples for laboratory testing. Fifteen of the sites were drilled to varying depths. Borehole logs from the drilled sites, along with additional drilling data obtained from ODOT archives, were used to verify the stratigraphic cross-sections prepared in the field. Twenty three additional sites were later added for a more intensive investigation of various aspects of undercutting-induced failures within inter-layered sequences of competent and incompetent rock and the instability caused by raveling of incompetent rock. Laboratory tests included determining density, point load strength index (Is_{50}), and second cycle slake durability index (Id_2) for both competent and incompetent rock samples, and plasticity index (PI) for all incompetent rock samples.

Based on their stratigraphy and modes of failure, the sedimentary rocks of Ohio were divided into three design units with respect to slope design: i) competent rock design unit, consisting mostly of sandstones, limestones, and siltstones, exhibiting discontinuity-related failures, (ii) incompetent rock design unit, consisting mostly of shales, claystones, and mudstones, exhibiting raveling and gulley erosion, and (iii) inter-layered rock design unit, consisting of both competent and incompetent rock units, exhibiting undercutting-induced failures. The field and lab data were used to perform a series of slope stability analyses for the three design units. RockPack and Dips software were used for kinematic analysis, SLIDE software was used to evaluate the potential for a deep-seated rotational failure, the Franklin shale rating system and ODOT's GB 3 methodology were used to determine the stable slope angles, and RocFall software was used to design benches and catchment ditches.

Findings

1. Kinematic analysis indicates that slopes cut at 0.5H:1V (63°) and 0.25H:1V (76°) are appropriate for competent rock design units. Friable sandstones should be treated as a special case, however, and would require a 1H:1V slope.
2. SLIDE analysis indicates that a deep-seated rotational failure is unlikely to occur at any of the study sites.
3. The Franklin shale rating system suggests that slope angles of 21-66 degrees for incompetent rock design units and 24-64 degrees for inter-layered rock design units would be stable.
4. Relationships between Id_2 and stable slope angles, as indicated by the Franklin shale rating system, were developed in this study.

Using these relationships, slopes in incompetent rock design units can be cut at < 2H:1V (26°)–0.5H:1V (63°) and those in inter-layered rock design units can be cut at 2H:1V (26°)-0.5H:1V (63°). Redbeds should be addressed on a case-by-case basis.

5. RocFall analysis shows that either a 13 ft (3.9 m) wide by 1ft (0.3 m) deep catchment ditch with a 10 ft (3 m) wide bottom and a 3H:1V foreslope or a 16 ft (4.8 m) wide by 1 ft (0.3m) deep ditch with a 10 ft (3 m) wide bottom and a 6H:1V foreslope would adequately retain at least 95% of the rockfalls, as long as the slope height does not exceed a certain limit. For higher slopes, either rockfall barriers or wider and deeper catchment ditches would be required. This study suggests the use of a barrier before a wider and deeper catchment ditch for economic and/or space limitation reasons.
6. RocFall analysis also suggests placing a bench at 100 ft (30 m) height for each of the three design units.
7. An adequate drainage system, with inter-connected drains, must be provided for all cut slopes.

Conclusions & Recommendations

Cut slope design in Ohio should be based on the stratigraphic conditions present at the construction site. The basic premise of the design should be to reduce the discontinuity-related failures in competent rock design units, decrease the amount of surficial weathering in incompetent rock design units, and minimize the potential for undercutting-induced failures in inter-layered rock design units. This can be accomplished through a combination of appropriate slope angles, bench locations, catchment ditches, rockfall barriers, and drainage systems.

It is recommended that temporal data about slope performance be collected on a regular basis, using LiDAR scanning.

Implementation Potential

The cut slope design methodology developed in this study can be used by ODOT and its consultants for designing new cut slopes as well as for remediating existing cut slopes. Applying the proposed methodology will minimize the current slope stability problems, will prolong the service life of cut slopes, and will result in uniform design across the state. The proposed methodology is summarized in the form of five tables included at the end of this report. Based on the findings of this study, a step-by-step manual for cut slope design has been prepared by the consultants associated with this project.