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SEISMIC DESIGN OF SEGMENTAL RETAINING WALLS

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INTRODUCTION

This TEK describes a method of analysis and design for conventional (gravity) and geosynthetic reinforced segmental retaining walls (SRWs) under seismic loading conditions. The methodology summarized herein extends the NCMA approach published in the NCMA *Design Manual for Segmental Retaining Walls* (ref. 1) for structures under static loading to simple structures that may be required to resist additional dynamic loads due to earthquakes. The seismic design method described briefly in this TEK, and in detail in the NCMA *Segmental Retaining Walls - Seismic Design Manual* (ref. 5), adopts a pseudo-static approach and uses the Mononobe-Okabe (M-O) method to calculate dynamic earth forces. The methodology adopts many of the recommendations contained in current AASHTO/FHWA guidelines for the design and analysis of Mechanically Stabilized Earth (MSE) structures subjected to modest earthquake loads (0.4g). However, the NCMA Segmental Retaining Walls - Seismic Design Manual - goes beyond the AASHTO/FHWA publications by addressing the unique stability requirements of segmental retaining walls that are constructed with a dry-stacked column of modular block units.

ASSUMPTIONS

The NCMA seismic design and analysis methodology applies when the following conditions are met:

- SRW structures are free-standing and able to displace horizontally at the base and yield laterally through the heights of the wall and at the wall crest.
- Reinforced and retained soils are cohesionless (i.e. purely frictional soils), unsaturated and homogeneous. Soil strength is described by the Mohr-Coulomb failure criterion. The apparent cohesive strength component of the free-draining soils is ignored, which is a conservative (i.e. safe) assumption for design.
- Maximum horizontal ground acceleration is 0.4g.
- Vertical ground acceleration is zero.
- Constant (infinite) backslope angle and constant horizontal foreslope angle.
- Retaining and reinforced soils are placed to a depth corresponding to the full height of the stacked standard facing units.
- Capping units (if present) are assumed to have a negligible effect on stability analyses assuming that they are attached to the facing column in such a manner that they cannot be dislodged during ground shaking.
- The stabilizing influence of wall embedment is ignored with the exception of bearing capacity analyses in which wall embedment is treated as an infinite uniform dead load surcharge.
- No permanent surcharge or footing loads exist at the top or behind the facing column.
- The base of the facing column is horizontal.
- Global instability involving failure of soil volumes beyond the base of the facing column and/or geosynthetic reinforced soil zone is not considered.
- SRW structures are built on competent foundations for which excessive settlement, squeezing, or liquefaction are not potential sources of instability.

A limitation of the pseudo-static seismic method of design proposed in this document is that it can only provide the designer with an estimate of the margins of safety against collapse of segmental retaining walls, or failure of their components, and does not provide any direct estimate of anticipated wall deformations. This is a limitation that is common to all limit-equilibrium methods of design in geotechnical engineering.

GEOSYNTHETIC REINFORCED SEGMENTAL RETAINING WALLS - MODES OF FAILURE

Stability analyses for geosynthetic reinforced segmental wall systems under static and seismic loading conditions involve separate calculations to establish factors of safety against external, internal, and facing modes of failure (Figure 1).

External stability calculations consider the reinforced soil zone and the facing column as a monolithic gravity structure. The evaluation of factors of safety against base sliding,

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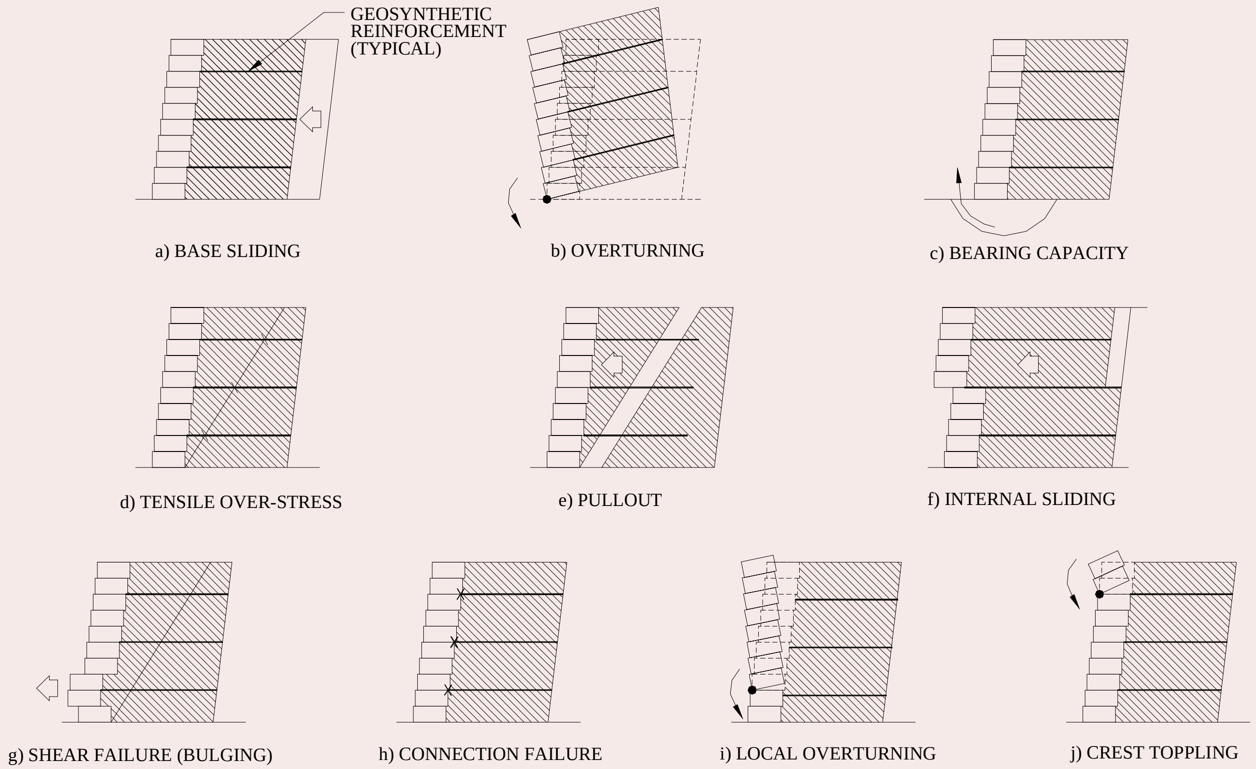

Figure 1—SRW Failure Modes for Stability Analysis

overturning about the toe, and foundation bearing capacity is similar to that used for conventional reinforced concrete masonry gravity structures.

Internal stability analyses for geosynthetic reinforced soil walls are carried out to ensure that the structural integrity of the reinforced zone is preserved with respect to reinforcement over-stressing within the reinforced zone, pullout of geosynthetic reinforcement layers from the anchorage zone, and internal sliding along a reinforcement layer.

Facing stability analyses are carried out to ensure that the facing column is stable at all elevations above the toe of the wall and connections between the facing units and reinforcement layers are not over-stressed.

Minimum recommended factors of safety of static *and* seismic design of geosynthetic reinforced SRW structures are given in Table 1.

In general, minimum recommended factors of safety for seismic design are taken as 75% of the values recommended for statically loaded structures following AASHTO/FHWA practice.

Potential settlement of reinforced SRW structures due to compression, liquefaction, or squeezing of foundation

TABLE 1—Recommended Minimum Factors of Safety for Design of Geosynthetic Reinforced SRW Structures

Failure Mode			Static	Seismic
a)	Base Sliding	FS_{sl}	1.5	1.1
b)	Overturning	FS_{ot}	1.5	1.1
c)	Bearing Capacity	FS_{bc}	2.0	1.5
d)	Tensile over-stress	FS_{os}	1.0	1.0
e)	Pullout	FS_{po}	1.5	1.1
f)	Internal Sliding	FS_{sli}	1.5	1.1
g)	Shear (bulging)	FS_{sc}	1.5	1.1
h)	Connection	FS_{cs}	1.5	1.1
i)	Local Overturning	FS_{otl}	1.5	1.1
j)	Crest Toppling	FS_{otc}	1.5	1.1
k)	Global Stability	FS_{g1}	1.3-1.5	1.1

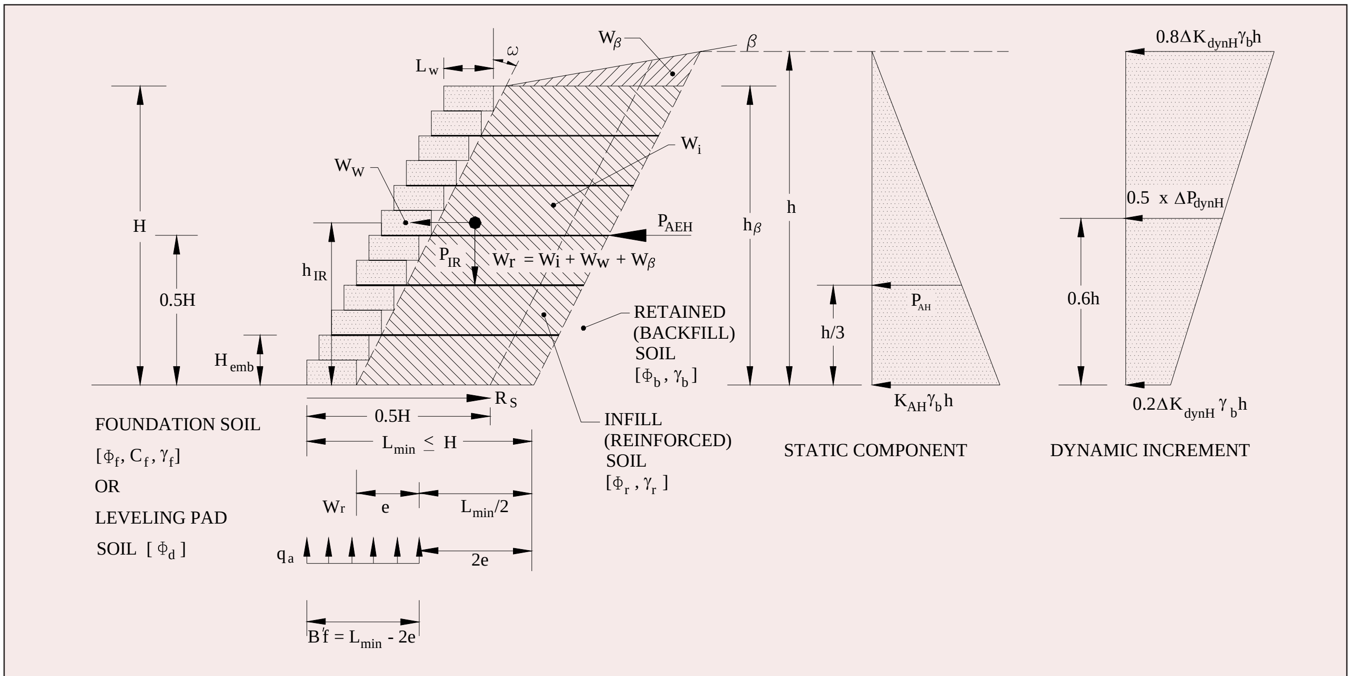

Figure 2—Geometry and Forces Used in External Stability Calculations for Reinforced SRW Structures

soils is not considered here. Separate calculations for foundation-induced deformations may be required by the designer. In addition, slope instability involving volumes of soil beyond and below the base of the facing column is not considered. Slope stability computer programs are available that can consider the effect of both the stabilizing influence of reinforcement layers and destabilizing influence of seismic-induced ground acceleration (ref. 2).

EXTERNAL STABILITY

External stability calculations are similar to those carried out for conventional static conditions with the addition of a dynamic earth pressure.

This dynamic earth pressure shown in Figure 2 is used to calculate the destabilizing forces in otherwise conventional expressions for the factor of safety against sliding along the foundation surface, overturning about the toe of the structure, and bearing capacity failure of the foundations soils. The simplified geometry and body forces illustrated in Figure 2 are used in the external stability calculations.

INTERNAL STABILITY

The contributory area approach (ref. 1, Sec 5.6.2.4) used for the static stability analysis of segmental retaining walls is extended to the dynamic loading case (Figure 3). In this method, the reinforcement layers are modelled as tie-backs with the tensile force F_i in layer i equal to the earth pressure integrated over the contributory area S_{vi} at the back of the facing column plus the corresponding wall inertial force increment. Hence:

$$F_i = k_h(int)\,\Delta W_{wi} + F_{sta\,i} + F_{dyn\,i}$$

where: $k_h(int)\,\Delta W_{wi}$ = wall inertial force increment; $F_{sta\,i}$ = static component of reinforcement load; and $F_{dyn\,i}$ = dynamic

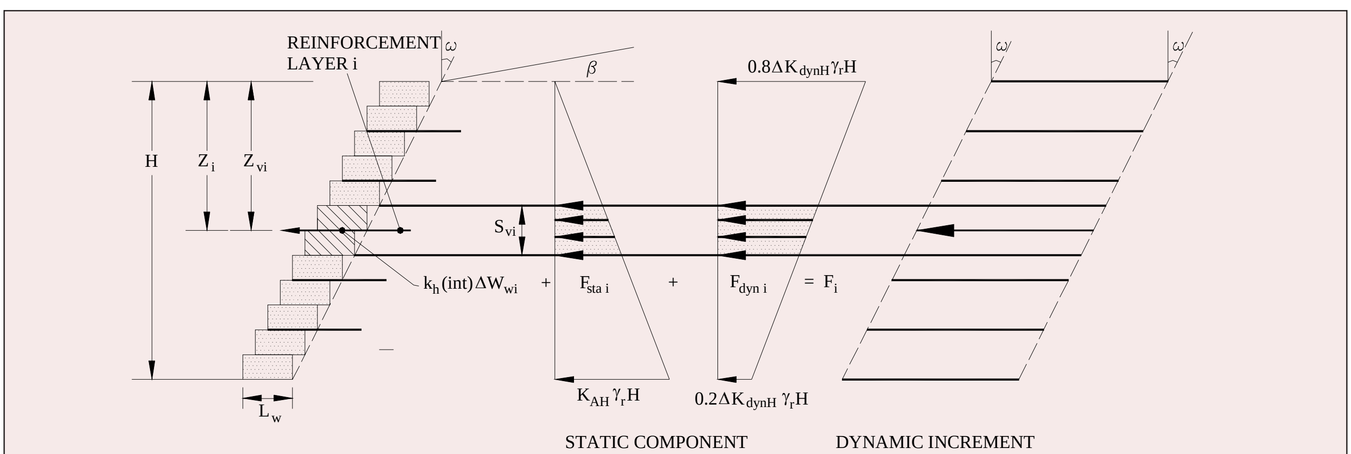

Figure 3—Geometry and Forces Used to Calculate Reinforcement Loads for Reinforced SRW Structures

component of reinforcement load.

Internal stability calculations are also similar to those carried out for conventional static conditions with the inclusion of dynamic earth pressure. Figure 3 shows the static and dynamic earth pressure distribution for internal stability calculations. The actual calculations for internal stability mirror the calculations for the static case and are presented in detail in ref. 5.

FIELD PERFORMANCE

The performance of SRWs during earthquakes is generally considered to be excellent (ref. 2). Observations of SRWs within 31 miles (50 km) of the epicenter of both the Loma Prieta earthquake and the Northridge earthquake have shown that this type of retaining wall system can withstand considerable horizontal and vertical accelerations without experiencing unacceptable deformations.

The design procedures developed and presented by NCMA in the first edition of the *Segmental Retaining Walls - Seismic Design Manual*, provide the design community with a rational, detailed design methodology which, if followed, will allow designers to take advantage of the SRW technology to build safe and economically feasible retaining walls to withstand seismic forces.

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