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# Chapter 12 Rock Material Field Classification System

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# Acknowledgment

**John S. Moore,** national hydrogeologist, Natural Resources Conservation Service, Washington, DC, prepared chapter 12 of part 631 of the National Engineering Handbook.

# Chapter 12 Rock Material Field Classification System

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## 631.1210 The rock material field classification system

### (a) Scope

The NRCS uses the Rock Material Field Classification (RMFC) system to classify rock and assess rock performance for several engineering applications of rock. The system is designed for use by personnel trained in its use and knowledgeable of its limitations. It is particularly suited to describing rock material in support of NRCS engineering activities at the reconnaissance and preliminary (planning) levels. Classification (by any system) alone does not preclude or replace laboratory testing for specific engineering design purposes.

### (b) History of RMFC system

The RMFC system was first issued in 1984 as SCS Technical Release 71. It was prepared by Louis Kirkaldie (SCS, retired), Peter V. Paterson (SCS, retired), and Douglas A. Williamson (USDA, Forest Service, retired). The second edition of TR-71, issued in 1987, had revisions made by John S. Moore. A critique of this edition was published in ASTM STP-984 (Moore, 1988). The edition presented here was prepared under the guidance of John S. Moore, NRCS geologist. Classification criteria for two engineering performance objectives, hydraulic erodibility in earth spillways and excavation characteristics were updated to reflect recent findings from field and laboratory research. Other performance objectives were updated to conform to the field procedures for describing various rock parameters presented in NEH 628.52.

### (c) Rock unit

The rock unit is the basic mapping unit for the RMFC system. It is defined as a body of rock that is identified in the field and mapped according to measurable or otherwise describable physical properties or features at a scale useful for project analysis. A rock unit is consistent in its mineralogical composition, geologic structure, and hydraulic properties. Its boundaries are delineated by measurable or otherwise describable physical properties or features. It is traced in the field by surface and subsurface mapping techniques. The body is prevailingly, but not necessarily, tabular in form; uniformity in thickness is not a determining factor. Because the mapping criteria are performance based engineering characteristics, rock units need not conform to formally recognized stratigraphic rock formations. The term rock unit is similar to lithosome in that the body of rock has consistent, mappable characteristics, but differs in that the body need not have been formed under uniform physicochemical conditions.

### (d) Outcrop confidence level

Outcrop confidence is the relative measure of the predictability or homogeneity of the structural domain and the lithology of the rock unit from one exposure to another or to the proposed site of investigation. The three levels of outcrop confidence are defined as:

**Level 1: High**—Rock units are massive and homogeneous, and are vertically and laterally extensive. Site geology has a history of low tectonic activity.

**Level II: Intermediate**—Rock characteristics are generally predictable, but have expected lateral and vertical variability. Structural features produced by tectonic activity tend to be systematic in orientation and spacing.

**Level III: Low**—Rock conditions are extremely variable because of complex depositional or structural history, mass movement, or buried topography. Significant and frequent lateral and vertical changes can be expected.

Once a rock unit has been established, it can be defined by classification elements and analyzed for performance in relation to selected performance objectives.

## (e) Classification elements

Classification elements are objective physical properties of a rock unit that define its engineering characteristics. Engineering classification of a rock unit takes into consideration the material properties of the rock itself, the structural characteristics of the in situ rock mass, and the flow of water contained in the rock or within the system of discontinuities. The RMFC system uses three major types of classification elements: rock material properties, rock mass properties, and geohydrologic properties.

### (1) Rock material properties

Rock material properties are measurable or otherwise describable lithologic properties of intact rock material that can be evaluated in hand specimen and thus can be subjected to meaningful inquiry in the laboratory. Rock material properties are related to the physical properties of the constituent minerals and the type of mineral bonding. The properties are determined from examination of hand specimens, core sections, drill cuttings, outcroppings, and disturbed samples using qualitative procedures and simple classification tests, or in the laboratory using standard test methods. The results are applicable to hand specimens and representative samples of intact rock material. They do not account for the influence of discontinuities or boundary conditions of the rock. Typical classification elements include:

- Principal rock type (see NEH 628, appendix 52C, table 4)
- Mineralogy (estimate percentage of principal and accessory minerals; note type of cement and presence of alterable minerals)
- Primary porosity (free draining or not)
- Discrete rock particle size (use D50 or cube root of the product of its three dimensions)
- Hardness category (use NEH 628, appendix 52C, table 5)
- Unconfined compressive strength (use NEH 628, appendix 52C, table 5)
- Unit weight (dry) (use NEH 628, appendix 52C, table 3)
- Color (use NEH 628, appendix 52C, table 1)

### (2) Rock mass properties

Rock mass properties are measurable or otherwise describable lithologic properties, characteristics, or features of the rock mass that must be evaluated on a macroscopic scale in the field. They include many types of discontinuities, such as fractures, joints, and faults, as well as abrupt changes in lithology because of erosion, deposition, or the effects of its mode of emplacement. Normally, rock mass properties are too large or extensive to be observed directly in their entirety at a single outcrop and are difficult or impossible to sample for laboratory analysis. Typical classification elements include:

- Discontinuity type (use NEH 628, appendix 52C, table 12)
- Joint set spacing category (use NEH 628, appendix 52C, table 11)
- Joint persistence category (use NEH 628, appendix 52C, table 13)
- Aperture category (use NEH 628, appendix 52C, table 14)
- Joint count number (use NEH 628.52, table 52-6)
- Roughness condition of joint walls (use NEH 628, appendix 52C, table 9)
- Type of joint infilling (gouge) (use NEH 628, appendix 52C, table 10)
- Large geomorphic features (karst topography, lava flows, lineaments, exfoliation)
- Large geologic structures (folds, faults, unconformities)
- Types of major voids (caverns, vugs, sinkholes, lava tubes)
- Seismic velocity (seismic refraction survey, use ASTM D 5777, Standard Guide for Using the Seismic Refraction Method for Subsurface Investigation)
- RQD (use ASTM D 6032, Standard Test Method for Determining Rock Quality Designation (RQD) of Rock Core)
- Other geophysical survey parameters (ground penetrating radar, gravity, electromagnetic, resistivity, use ASTM D 6429, Guide for Selection of Surface Geophysical Methods)

The properties of a rock mass are often significantly different from the properties of intact rock samples of the same rock mass. The mechanical behavior and strength of a rock mass are commonly dominated more by mass properties than by material properties. For example, a rock mass composed of the strongest intact rock material is weakened in proportion to the number of discontinuities in a given volume. Material properties, on the other hand, dominate the strength of a rock mass where discontinuities are widely spaced or nonexistent. Thus, discontinuities inevitably lower the strength and stability of a rock mass and reduce the amount of energy required to excavate, erode, remove, blast, or otherwise destabilize the rock mass.

### (3) Geohydrologic properties

Geohydrologic properties are attributes of a rock unit that affect the mode of occurrence, location, distribution, and flow characteristics of subsurface water within the unit. Geohydrologic properties include material and mass properties, but also account for the interaction and behavior of subsurface water within the rock mass. Field tests are typically used to evaluate geohydrologic properties of the rock mass, including secondary porosity, hydraulic conductivity, transmissivity, and other hydraulic parameters. Laboratory tests are used to evaluate geohydrologic properties of the rock material, such as primary porosity and permeability. Typical classification elements include:

- Primary porosity (use data collected for rock material properties)
- Secondary porosity (use data collected for rock mass properties)
- Hydraulic conductivity (pump tests, published information)
- Transmissivity (pump tests, published information)
- Storativity/specific yield (pump tests, published information)
- Soluble rock (occurrence of limestone, gypsum, or dolomite; see data collected for rock material properties)
- Water table/potentiometric surface (measured in field, published data, date of measurement)
- Aquifer type (unconfined, confined, leaky artesian, perched)
- Electrical conductivity (geophysical survey)

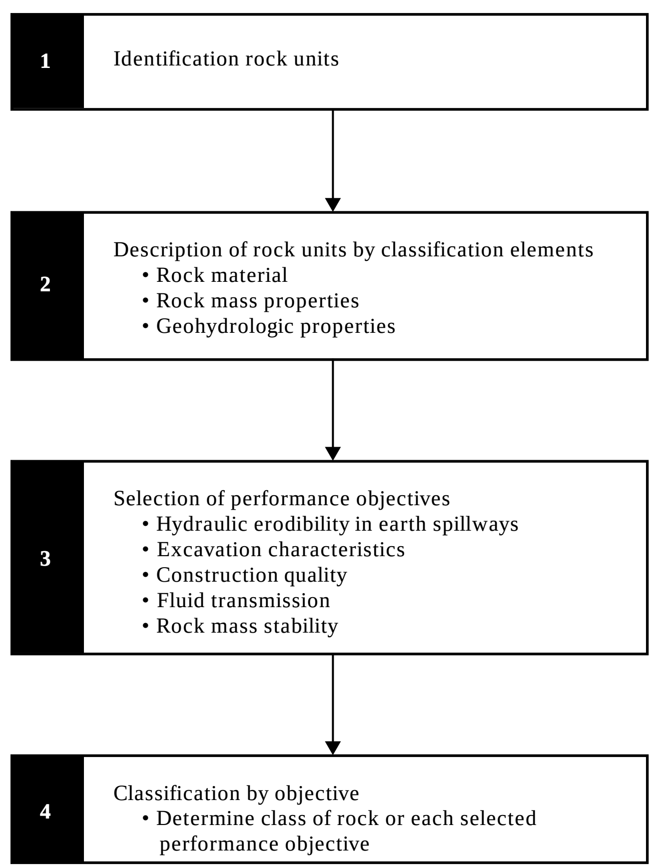
## (f) Classification process

The classification process consists of identifying the rock units at the site of investigation, describing them in terms of appropriate classification elements, and conducting the performance assessment. The performance assessment includes selecting the performance objectives for the proposed engineering uses of the rock and classifying the rock material within each selected objective. Figure 12–1 schematically illustrates the basic steps in the process.

### (1) Identify rock units

Rock unit identification includes determining the location and extent of each mappable unit in outcrop or in stratigraphic section at and near the site. When done in conjunction with a review of available data, maps, and literature, this fieldwork should provide the outcrop confidence level. If a formally recognized geologic formation is expected to perform as a homogeneous mass for engineering purposes, it may be considered a rock unit (as defined in this chapter) and identified by its formal stratigraphic name, such as Vishnu schist. All other mappable rock units should be assigned alphanumeric designations, such as Rock Unit L-6. Each unit should be located on a geologic map by stationing, depth, and elevation. The outcrop confidence level should be determined and recorded in the notes.

**Figure 12–1** Process for using the Rock Material Field Classification system



### (2) Describe rock units by classification elements

Each rock unit is characterized in terms of specific classification elements that affect performance of the rock for its intended use. The investigator may include any additional elements considered necessary for further clarification and refinement.

**Rock material properties**—Determined by examining and classifying hand specimens, core sections, drill cuttings, outcroppings, and disturbed samples using conventional geologic terminology.

**Rock mass properties—**Determined by geologic mapping, fixed line survey, geophysical survey, remote imagery interpretation, core sample analysis, and geomorphic analysis.

**Geohydrologic properties**—Determined by pressure testing; review of logs/data from water wells, observation wells, drill holes, and piezometers; review of published and unpublished maps and reports; interpretation of rock material and rock mass properties; and dye tests.

### (3) Select performance objectives

This step involves the selection of performance objectives (engineering uses) of the rock for which an assessment of engineering performance is needed. Tables 12–1 through 12–5 provide the criteria for applicable classification elements that define each class for the five performance objectives considered in this system.

For hydraulic erodibility in earth spillways, use table 12–1, which covers evaluation of erodibility of rock subject to intermittent flowing water.

For excavation characteristics, use table 12–2, which covers evaluation of excavation characteristics of rock.

For construction quality, use table 12–3, which covers analysis of rock quality for riprap, aggregate, embankment fill, and road armor for construction applications.

For water transmission, use table 12–4, which covers evaluation of the potential for water transmission through primary and secondary porosity in rock units underlying reservoirs, canals, and dam foundations; for excavation dewatering; for engineering subdrainage for slope stability and for point and nonpoint source pollution; for ground water yield for water supply development (water wells, springs, aquifers, basins) for ground water recharge or disposal; and for salt water intrusion.

For rock mass stability, use table 12–5, which covers evaluation of rock mass stability of natural or constructed slopes for gravity or seismic activity.

### (4) Classification by objective

Determining the class of the rock material for all identified performance objectives is the final step in the procedure. Each of the five performance objectives has three classes of rock material (tables 12–1 through 12–5). A class defines the expected capabilities and limitations of the rock for each engineering use. End member classes I and III for each performance objective are intentionally defined restrictively. Therefore, rock material that classifies as class II is usually an indication that additional evaluation may be needed than just what is considered in the tables. Rock units assigned to the same class within a given performance objective can be expected to perform similarly.

**Table 12–1** Hydraulic erodibility in earth spillways

| Classification elements | Class I | Class II | Class III |
|---|---|---|---|
| | **Highly erosion resistant** | **Erosion resistant** | **Moderately erosion resistant** |
| | Rock material experiences headcut erosion rates less than 0.3 m/hr (1 ft/hr) at a unit discharge of 9.2 $m^3$/s/m (100 $ft^3$/s/ft) and 9 m (30 ft) of energy head. Must fulfill the following condition: | Rock material experiences headcut erosion rates from 0.3 to 3.0 m/hr (1 to 10 ft/hr) at a unit discharge of 9.2 $m^3$/s/m (100 $ft^3$/s/ft) and 9 m (30 ft) of energy head. Must fulfill the following condition: | Rock material experiences headcut erosion rates greater than 3.0 m/hr (10 ft/hr) at a unit discharge of 9.2 $m^3$/s/m (100 $ft^3$/s/ft) and 9 m (30 ft) of energy head. Must fulfill the following condition: |
| Headcut erodibility index, $k_h$ (NEH 628.52), which comprises:<br>Material strength<br>Block size<br>Discontinuity shear strength<br>Relative ground structure | $k_h \geq 100$ | $10 < k_h < 100$ | $1 \leq k_h \leq 10$ |

**Table 12–2** Excavation characteristics

| Classification elements | Class I | Class II | Class III |
|---|---|---|---|
| | **Very hard ripping to blasting** | **Hard ripping** | **Easy ripping** |
| | Rock material requires drilling and explosives or impact procedures for excavation may classify [1] as rock excavation (NRCS Construction Spec. 21). Must fulfill **all** conditions below: | Rock material requires ripping techniques for excavation may classify [1] as rock excavation (NRCS Construction Spec. 21). Must fulfill **all** conditions below: | Rock material can be excavated as common material by earthmoving or ripping equipment may classify [1] as common excavation (NRCS Construction Spec. 21). Must fulfill the **all** conditions below: |
| Headcut erodibility index, $k_h$ (NEH 628.52) | $k_h \geq 100$ | $10 < k_h < 100$ | $k_h \leq 10$ |
| Seismic velocity, approximate (ASTM D 5777 and Caterpillar Handbook of Ripping, 1997) | ≥ 2,450 m/s (≥ 8,000 ft/s) | 2,150–2,450 m/s (7,000–8,000 ft/s) | ≤ 2,150 m/s (≤ 7,000 ft/s) |
| Minimum equipment size (flywheel power) required to excavate rock. All machines assumed to be heavy-duty, track-type backhoes or tractors equipped with a single tine, rear-mounted ripper. | 260 kW (350 hp), for $k_h < 1,000$<br>375 kW (500 hp), for $k_h \leq 10,000$<br>Blasting, for $k_h > 10,000$ | 185 kW (250 hp) | 110 kW (150 hp) |

1/ The classification in no way implies the actual contract payment method to be used or supersedes NRCS contract documents. The classification is for engineering design purposes only.

**Table 12–3** Construction quality

| Classification elements | Class I | Class II | Class III |
|---|---|---|---|
| | **High grade** | **Medium grade** | **Low grade** |
| | Rock material is suitable for high stress aggregate, filter and drain material, riprap, and other construction applications requiring high durability. Must fulfill **all** conditions below: | Rock material is potentially suitable for construction applications. May require additional evaluation if **at least one** condition below is fulfilled: | Rock material is unsuitable for aggregate, filter, and drain material, or riprap. Reacts essentially as a soil material in embankments. Must fulfill **at least one** condition below: |
| Strength (NEH 628.52, table 52–4) | > 50 MPa (> 7,250 lb/in$^{2}$) | 12.5–50 MPa (1,800–7,250 lb/in$^{2}$) | < 12.5 MPa (< 1,800 lb/in$^{2}$) |
| Hardness (NEH 628.52, table 52–4) | Hard to extremely hard rock | Moderately hard rock | Moderately soft to very soft rock |
| Unit weight (NEH 628.52, appendix 52C, table 3) | > 2.24 g/cm$^{3}$ (> 140 lb/ft$^{3}$) | 2.08–2.24 g/cm$^{3}$ (130–140 lb/ft$^{3}$) | < 2.08 g/cm$^{3}$ (< 130 lb/ft$^{3}$) |

**Table 12-4** Fluid transmission

| Classification elements | Class I | Class II | Class III |
|---|---|---|---|
| | **Slowly permeable** | **Moderately permeable** | **Highly permeable** |
| | Rock material has low capability to transmit water. Must fulfill **all** conditions below. | Rock material has potential to transmit water, generally through primary porosity.May require additional evaluation if **at least one** condition below is fulfilled. | Rock material has high capability to transmit water, generally through secondary porosity. Must fulfill **at least one** condition below. |
| Soluble rock | No soluble rock occurs in the rock mass. | Soluble rock, if present, occurs as a minor or secondary constituent in the rock mass | Soluble rock, such as lime stone, gypsum, dolomite, marble, or halite, is the predominant rock type. |
| Primary porosity | Very low primary porosity; pores not interconnected or free draining | Pores visible under l0x hand lens; slowly free draining | Pores visible to naked eye; rapidly free draining |
| Number of joint sets (include bedding plane partings) | 1 joint set and random fractures; or rock mass intact and massive | ≤ 2 joint sets and random fractures | ≥ 3 interconnecting joint sets |
| Joint aperture category (NEH 628.52, appendix 52C, table 14) | Extremely narrow, hairline (<2 mm) | Very narrow to narrow (2–6 mm) | Narrow to wide (≥ 6 mm) |
| Infilling (gouge) | Joints tight or filled with cohesive, plastic clay or swelling fines matrix | Joints open or filled with nonplastic, nonswelling fines matrix | Joints open or filled with sand or gravel with < 15% cohesionless, nonplastic fines matrix |
| Major voids, solutional (caverns, sinkholes, enlarged joints), depositional (lava tubes or interbedded gravels and lava beds) or structural/tectonic (faults, stress relief joints) | No major voids occur in rock mass | | Any types of major voids occur in rock mass |
| Hydraulic conductivity (dams) | $< 10^{-6}$ m/s (< 0.3 ft/d) | | $> 10^{-5}$ m/s (> 3 ft/d) |
| Transmissivity (irrigation wells) | $< 10^{-3}$ $m^2/s$ ($< 10^3$ $ft^2/d$) | | > 1 $m^2/s$ ($> 10^5$ $ft^2/d$) |
| Transmissivity (domestic/ stock wells) | $< 10^{-6}$ $m^2/s$ (< 1 $ft^2/d$) | | $> 10^{-4}$ $m^2/s$ ($> 10^2$ $ft^2/d$) |

**Table 12–5** Rock mass stability

| Classification elements | Class I | Class II | Class III |
|---|---|---|---|
| | **Stable** | **Potentially unstable** | **Unstable** |
| | Rock material has very low potential for instability. Must fulfill **all** conditions below: | Rock material has potential for instability. May require additional evaluation if **at least one** condition below is fulfilled: | Rock material has significant potential for instability. Must fulfill **at least** one condition below: |
| Strength (NEH 628.52, table 52–4) | > 50 MPa (> 7,250 lb/in$^2$) | 12.5–50 MPa (1,800–7,250 lb/in$^2$) | < 12.5 MPa (< 1,800 lb/in$^2$) |
| Hardness (NEH 628.52, table 52–4) | Hard to extremely hard rock | Moderately hard rock | Moderately soft to very soft rock |
| RQD (ASTM D 6032) | > 75 | 25–75 | < 25 |
| Number of joint sets in rock mass (include bedding plane partings) | 1 joint set and random fractures, or rock mass intact and massive; no adverse component of dip | ≤ 2 joint sets plus random fractures; no set contains adverse component of dip | ≥ 3 interconnecting joint sets; and ≥ 1 set contains adverse component of dip |
| Joint water condition | Unconfined | Unconfined | Confined |

# 631.1220 Evaluating earth material for excavation by a ripping index

## (a) Purpose

NRCS Construction Specification 21, Excavation, provides criteria for defining rock excavation and common excavation, for pay purposes. One of the criteria defining rock excavation is the need to use either heavy ripping equipment (rated above 250 flywheel horsepower) or blasting to achieve excavation. This section describes the ripping index method for predicting the excavatability of any earth material. The index allows estimation of the minimum energy or effort required for excavation, on a scale ranging from hand tools to drilling and blasting.

## (b) Background

An earth material classification system developed by Kirsten (1982 and 1988) was field proven by ripping trials to reasonably accurately predict the excavation characteristics of a broad range of earth material. Kirsten's ripping index, $k_n$, allows earth material to be classified on a continuous basis from soft soil through hard rock. Moore, Temple, and Kirsten (1994) developed the concept of a headcut erodibility index based on the analogy between bulldozer drawbar power required for ripping earth material and the hydraulic power associated with turbulent energy dissipation at a headcut. Both indexes comprise the same rock material and rock mass parameters. The classification system for the headcut erodibility index, $k_h$ (Temple and Moore, 1997) is part of the Earth Spillway Erosion Model described in NEH 628.51.

## (c) Ripping Index method

Excavation characteristics of any given earth material are readily established by calculating the material's ripping index. The ripping index is determined by following the same procedures used in determining the headcut erodibility index (NEH 628.52).

Table 12–6 correlates various parameters that indicate the excavatability of the full spectrum of earth material. In the first column, earth material is delineated by hardness. The second column provides the minimum tools required for excavation. The excavation class (rock or common), as defined in NRCS Construction Specification 21, Excavation, is provided in parentheses. Determining the ripping index or seismic velocity allows prediction of the minimum size machine needed (expressed in flywheel horsepower) to excavate the material. The final column indicates the class of rock for excavation characteristics (table 12–2) in the RMFC system.

**Table 12–6** Correlation of various indicators of earth material excavatability

| Earth material hardness | Excavation description excavation class | Ripping index [1] ($k_n$) | Seismic velocity [2] (ft/s) | Equipment [3] needed for excavation (hp) | RMFC system class (table 12–2) |
|---|---|---|---|---|---|
| Very soft through firm cohesive soil or very loose through medium dense cohesionless soil (NEH 628.52, tables 52–2 & 52–3) | Hand tools (common [4]) | < 0.10 | < 2,000 | — | — |
| Stiff cohesive soil or dense cohesionless soil through very soft rock or hard, rock-like material (NEH 628.52, tables 52–2 & 52–3) | Power tools (common [4]) | 0.10–1.0 | 2,000–5,000 | ≥ 100 | — |
| Soft through moderately soft rock (NEH 628.52, table 52–4) | Easy ripping (common [4]) | 1.0–10 | 5,000–7,000 | ≥ 150 | III |
| Moderately hard through hard rock (NEH 628.52, table 52–4) | Hard ripping (rock [5]) | 10–100 | 7,000–8,000 | ≥ 250 | II |
| Very hard rock (NEH 628.52, table 52–4) | Very hard ripping (rock [5]) | 100–1,000 | 8,000–9,000 | ≥ 350 | I |
| Extremely hard rock (NEH 628.52, table 52–4) | Extremely hard ripping to blasting (rock [5]) | 1,000 –10,000 | 9,000–10,000 | ≥ 500 | I |
| | Drilling and blasting (rock [5]) | > 10,000 | > 10,000 | — | I |

1/ Because ripping index, $k_n$, (Kirsten, 1988 and 1988) is equal to headcut erodibility index, $k_h$ (NEH 628.52), use $k_h$.
2/ Seismic velocity values are approximate, taken from ASTM D 5777 and Caterpillar Handbook of Ripping (1997).
3/ Flywheel horsepower, machines assumed to be heavy-duty, track-type backhoe or tractor equipped with a single tooth, rear-mounted ripper.
4/ Meets criteria for common excavation in NRCS Construction Specification 21, Excavation.
5/ Meets criteria for rock excavation in NRCS Construction Specification 21, Excavation.

**Note:** The classification in no way implies the actual contract payment method to be used or supersedes NRCS contract documents. The classification is for engineering design purposes only.

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