Bearings and Expansion Joints: Types of bearings elastomeric, pot, rocker, roller, and spherical; design principles for load transfer and rotation

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***Abstract*— "Structural comportments" is currently an introductory act intention of which is furnishing a good manufacturing quality and operation of ultramodern ground comportments. This act prepared during 17 times is a recapitulation of European gests on this field. It was the first harmonized European Standard on construction products. utmost of Standard corridor are innovative as compared with old public bones. As ground expansion gaps form discontinuities in pavement they beget dynamic and impact fresh loads. It has influence on continuity and trustability of ground expansion joints which are frequently complex mechanical structures. Their quality depends on conditions fulfillment given in R&BRI Technical blessings as well as in ETAG 032 Guideline. These conditions relate not only to assembly and installation perfection of expansion joints but also to their fatigue resistance verification. nevertheless, not only in Poland, further and further one can observe their damages and failures. utmost of failures are related to the shape of face noise reducing rudiments and system of their fastening.**

***Index Terms*— Bearings in Bridges, Expansion Joints in Bridges, Elastomeric Bearings, Pot Bearings, Rocker Bearings, Roller Bearings, Bearing Function and Mechanism, Load Transfer Mechanisms, Rotation Accommodation in Bearings, Bridge Movement and Restraint, Bridge Deck Expansion Control, Design Principles of Bearings Design Criteria for Expansion Joints, Bridge Durability and Maintenance, Seismic Performance of Bearings**

I. INTRODUCTION

Bearings and expansion joints are fundamental components in various engineering and infrastructure systems, particularly in mechanical machinery and civil structures such as bridges. Bearings facilitate relative motion between parts, reduce friction, and support loads, while expansion joints accommodate movement caused by thermal expansion, load shifts, or other dynamic factors, preserving structural integrity. Recent advances in both theoretical understanding and practical assessment methods for bearings and expansion joints have significantly improved system reliability and performance. This paper synthesizes recent research on bearing rigidity, bearing fault diagnosis, and expansion joint evaluation, highlighting the intersections between theoretical developments in rigidity theory, data-driven diagnostic techniques, and innovative non-contact Bearings and expansion joints are fundamental components in various engineering and infrastructure systems, data-driven diagnostic techniques, and innovative non-contact assessment methodolo-gies.

II. CLASSIFICATION OF BEARINGS

A bearing is an element of a ground structure which determines the continuity and trustability as well as its safety geste. In the middle of last century numerous innovative bearing designs were constructed. They're currently veritably popular in ground engineering.

Traditional generalities as breakers, rockers, leg sword plate and concrete hinges came literal results. Conditions for designing, manufacturing and installing bridge comportments have been fully changed. Besides of traditional sword grades in ultramodern ground comportments, we meet the accoutrements not used in the once e.g. austenite sword, silicone grease, PTFE, compound accoutrements as well as synthetic rubber and polyurethane. Since the 1970s the Road and Bridge Research Institute(R&BRI) is responsible for the supervision, control and preface to Polish ground engineering of ultramodern types of comportments. Till 2010 this task was fulfilled by blessing tests being base for specialized blessings issued by the Institute. After espousing EN 1337 as Polish Standard this exertion was intruded. But nearly 40 times of prototype and new on Polish request comportments tests allow to form at the Institute the competitive center for ultramodern ground comportments quality and trustability assessment, Niemierko(1994).

2.1 ELASTOMERIC BEARING

An elastomeric bearing is a type of structural bearing made primarily of rubber (elastomer) , either natural rubber (NR) or neoprene (CR) sometimes reinforced with thin steel plates (laminated type).It is designed to transfer loads from the superstructure to the substructure of a bridge while allowing controlled movements and rotations due to traffic loads, temperature changes, and shrinkage or creep concrete.

Fig 1 ;- elastomeric bearing

2.2 POT BEARING

Pot bearing is a kind of new type bearing which is composed of pot, elastomeric pad, pristine sword plate, sealing ring and other factors. It's designed for bearing the combinations of perpendicular loads, vertical loads, longitudinal and transverse deportations and reels.

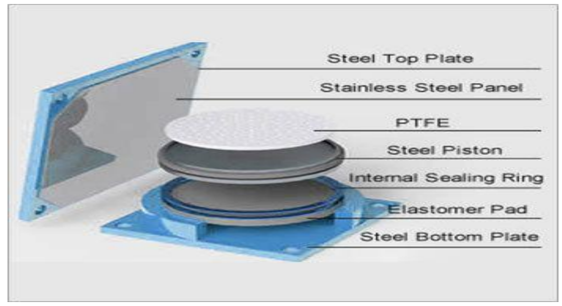


Fig 2 :- Pot Bearing

2.3 ROCKER BEARING

A rocker bearing is a type of bridge bearing that allows rotation and limited longitudinal movement of the superstructure while transferring vertical loads safely to the substructure. It operates on a rocking motion, similar to a hinge, to accommodate expansion and contraction caused by temperature changes or other movements.

Fig 3:- Rocker Bearing

2.4 ROLLER BEARING

A roller bearing is a type of bridge bearing designed to allow both rotation and translation (movement) of the bridge superstructure. It consists of steel rollers placed between two plates, permitting the deck to expand and contract freely while transmitting vertical loads to the substructure.

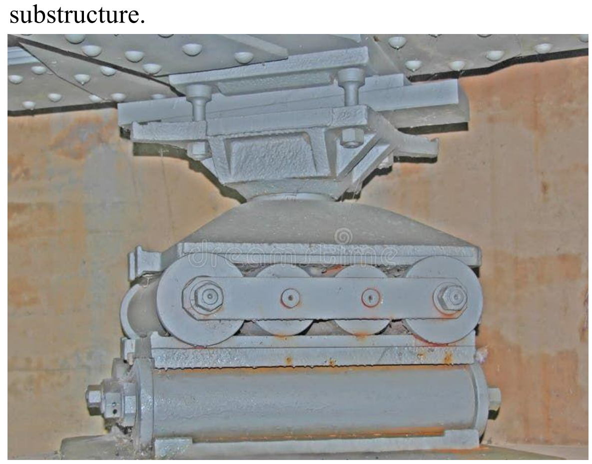


Fig 4 :- Roller Bearing

2.5 SPHERICAL BEARING

A spherical bearing (also called a spherical steel bearing or spherical hinge bearing) is a type of bridge bearing that allows rotation in all directions and, when combined with sliding or guided plates, can also permit controlled translational movement.

It uses a concave and convex surface interface, similar to a ball-and-socket joint, to provide smooth rotational motion under high vertical loads.

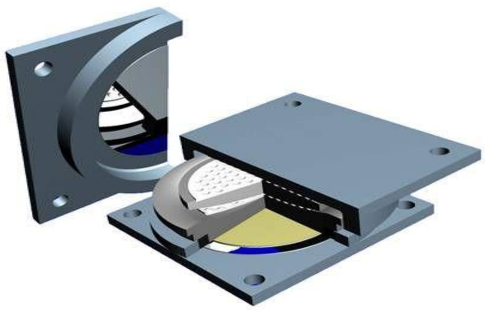


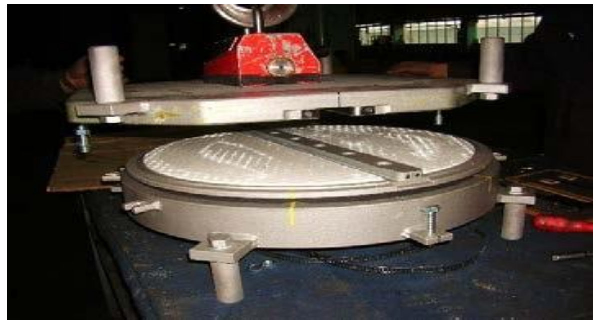
Fig 5 :- spherical Bearing

III. OBJECTIVE

1. Classify and describe different types of bearing including elastomeric, pot, rocker, roller, and spherical bearing and explain their functional behavior.
2. Understand the mechanism of load transfer through bearings and their role in allowing rotational and translational movements of bridge decks.
3. Study the design principles governing the selection of bearings for various structural and environmental conditions in accordance with international codes and standards.
4. Examine the role of expansion joints in accommodating bridge deck movements and minimizing stress concentration or damage at supports.
5. Identify common design and maintenance challenges associated with bearings and joints, ensuring durability, serviceability, and safety of bridge structures.

IV. SPHERICAL BEARING DESIGN PRINCIPLES FOR LOAD TRANSFER AND ROTATION

for the first time used in 1959 in Germany, Eggert (1978). Its conception is grounded onelastomeric pad confined in cylinder by means a close befitting piston and internal seal. This piston assures that the elastome can be subordinated to much lesser pressure and can bear as a visco-elastic material. In addition as insulated from external influence of ozone and UV radiation, it can be made with natural rubber conserving good pliantness in low temperature.



(a) and removed sliding plate

(b) In Poland first pot comportments

Pot bearing with central crucial allowing for movement in one direction(a) and removed sliding plate (b). In Poland first pot comportments with the R&BRI specialized support were manufactured by PRInż Katowice at the morning of 90s. Now pot comportments reach capacity of 200 MN with blockish shape of elastomer pad or 120 MN and for indirect one with periphery 2500 mm, Block et al.(2013).

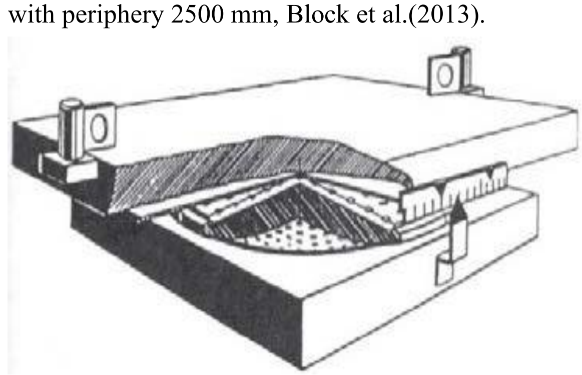


Fig. C.. Free sliding spherical bearing.

Spherical (Fig. 7) and spherical comportments are simply a kind of spatial articulation with contact shells covered by PTFE wastes. They can be combined with flat sliding element allowing vertical deportations of ground structure. The first globular bearing was installed in Germany in 1966. In Poland they were used in the first incrementally launched ground in 1987. Grounded on prototype tests accepted in R&BRI in 1980s one of lesser islands over Vistula swash was supported on 8 MN capacity globular comportments of own product. Unfortunately after some month of operation in consequence of indecorous use of sliding rudiments the PTFE wastes had been destroyed, Niemierko(1992). One of the biggest in Europe globular comportments are installed on two central supports of string- stayed ground over Vistula swash in Płock, Niemierko et al. (2006). Bearings of 110 MN capacity had 2200 mm periphery of rotational element

Fig. D Lowering of convex rotational element on Hollow backing plate of 110 MN capacity guided spherical bearing.

Quite new design in ultramodern ground comportments are companion comportments and restraint comportments(Fig. 9, 10 and 11). They're treated as special bias and in view of their lesser cost they're used only in maintainable cases, for illustration when typical comportments can not be applied. In general they are n't intended for transmitting perpendicular lading and bending moments but for allowance or blocking the displacements.They generally cooperate with comportments which transmit perpendicular lading.

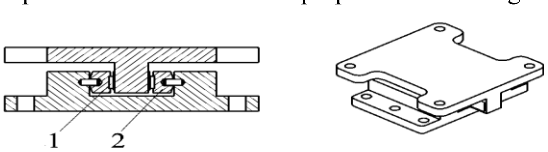


Fig. E. Example of Companion bearing; a – Sampling, b – axonometric view; 1 – sliding element, 2 – articulation.

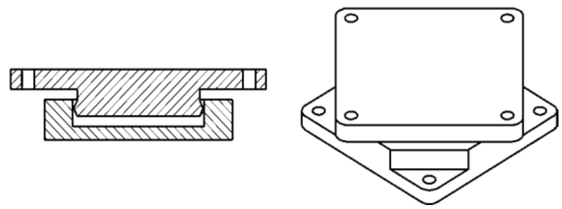


Fig. F illustration of restraint bearing; a – sampling, b – axonometric view.

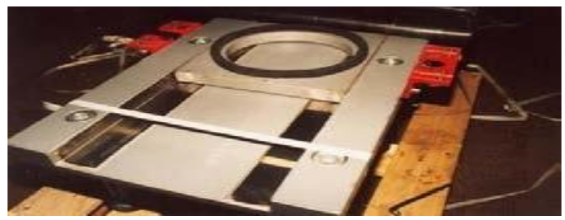


Fig. G. Guide bearing with lower sliding plate and portable element applied in Płock bridge.

3.1. Bearing's installation

For statically indeterminate or twisted and dispose ground structures it's important to install the comportments in agreement with design responses rather than in agreement with geometrical layout of the sundeck. Indeed small changes in supporting situations can give a rise to great changes in response distribution. It should be handed the relief or rectification of bearing by supplementary plates. Uplift responses should be rather avoided. In case of skew spans the fixed bearing should be installed in place where the topmost response is designed e.g. in blunt angle not in acute one. On one support can not be installed comportments with different compressibility. Final comportments should be installed after completion of whole ground structure. It is n't allowed to use the final comportments in ground sundeck construction stages e.g. for incremental launching or beforepost-tensioning of prestressed concrete structure. For nonstop multispan structures it's recommended to install a fixed bearing on one of intermediate supports(generally middle one). Such a result allows using the expansion joints with lower movement.

V.EXPANSION JOINTS

Ground expansion gaps form discontinuities in pavement causing fresh dynamic and impact loads. They've influence on the continuity and trustability of ground expansion joints, which are frequently complex mechanical structures. Their quality depends on conditions fulfillment given in R&BRI Technical blessings as well as ETAG 032 Guideline. These conditions relate not only to assembly and installation perfection of expansion joints but also to their fatigue resistance assessment. nevertheless, not only in Poland, further and further one can observe their damages and failures, Lachinger et al.(2014); Zimmermann, T. et al.(2014). utmost of failures are related to the shape of face noise reducing rudiments and system of their fastening. So it's recommended to extend the fatigue tests on expansion joints with face noise reducing rudiments. In 2006 under EOTA was formed Technical Committee for junction of expansion joints conditions. In 2013 the work was finished with elaboration of Guideline for European Specialized blessing of Expansion Joints for Road Islands(ETAG 032, Tab. 3). Now it serves as a base for the issue of European Assessment Documents (EAD).

Table 3. Corridor of ETAG 032.

Part	Title
1	General
2	Buried Expansion Joints (Fig. 12)
3	Flexible Plug Expansion Joints (Fig. 13)
4	Nosing Expansion Joints (Fig. 14)
5	Mat Expansion Joints (Fig. 15)
6	Stake Expansion Joints (Fig. 16)
7	Supported Expansion Joints (Fig. 17)
8	Modular Expansion Joints (Fig. 18)

Buried Expansion Joints (Fig. 12) are used for deportations not greater as 25-30 mm. Flexible Plug Expansion Joints (Fig. 13) are generally used for gap relegation not greater as 40 mm. Both are executed directly on point.

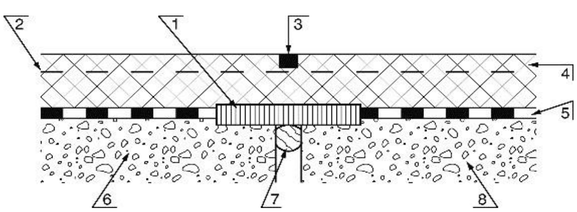
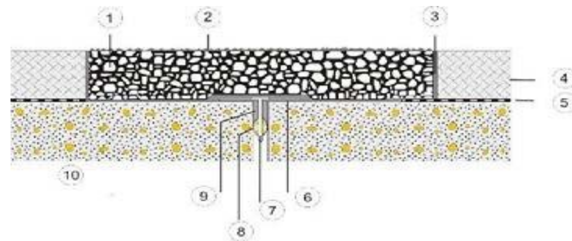


Fig. 4.1. Buried Expansion Joint acc. to ETAG 032-2: 1 – buried expansion joint, 2 – pavement underpinning, 3 – crack sealant, 4 – pavement, 5 – waterproofing, 6 – ground sundeck, 7 – caulking, 8 – abutment.



4.2. Flexible Plug Expansion Joint acc. to ETAG 032-3 1 – bituminous stuffing admixture, 2 face dressing, 3 – tanking, 4 – pavement, 5 – waterproofing, 6 – essence plate, 7 – fixing, 8 – caulking, 9 – sealant, 10 – ground sundeck.

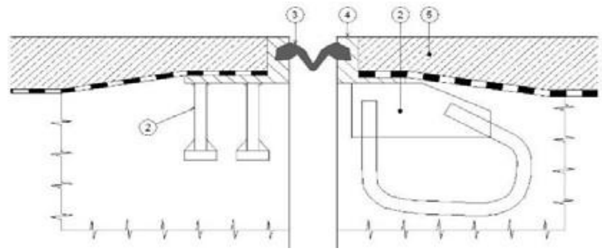


Fig. 4.3. Nosing Expansion Joint acc. to ETAG 032-4: 2 – anchorage, 3 – seal part, 4 – edge profile, 5 – pavement.

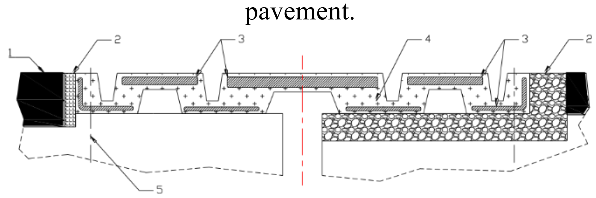


Fig. 4.4. Mat Expansion Joint acc. to ETAG 032-5: 1 – pavement, 2 (left side) – sealant, 2 (right side) – transition strip, 3 – reinforcement, 4 – elastomer, 5 – anchoring.

Fig. 4.5. Cantilever (Finger) Expansion Joint with clamping device.

Nosing Expansion Joints (Fig. 14) are used for gap displacement not greater as 80 mm. Mat Expansion Joints (Fig. 15) are used for gap displacement not greater as 330 mm. Cantilever Expansion Joints (Fig. 16) are used for gap displacement from 80 to 800 mm. Supported Expansion Joint (Fig. 17) is composed of finger elements forming sliding plate one end of which is anchored and another is supported with sliding possibility on the opposite side of gap. The second plate with fingers serving for refilling the space between fingers of sliding plate is attached on this side of gap.

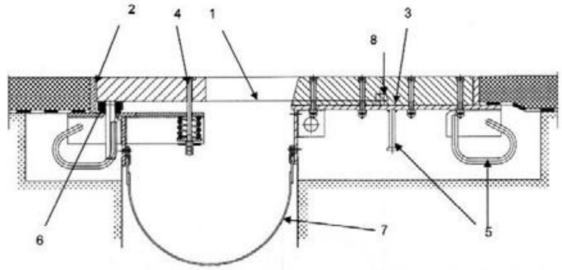


Fig. 4.5. Supported Expansion Joint acc. to ETAG 032-7: 1 – sliding plate, 2 – fixe support base, 3 – sliding support base, 4 – holding down device of sliding plate, 5 – anchorage system, 6 – support, 7 – gutter, 8 – sliding support.

Modular Expansion Joint (Fig. 18) gives the greatest movement possibility (over 800 mm). It is composed of subsequent beams with watertight sealants supported by crossbeams construction of which allow uniform expansion between beams.

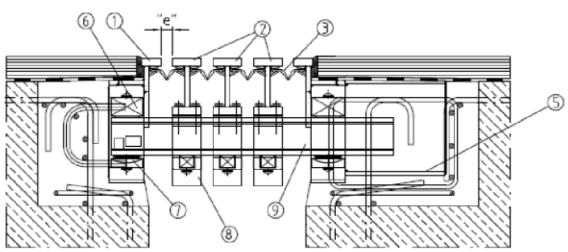


Fig. 4.6. Modular Expansion Joint acc. to ETAG 032-8; 1 – edge beam, 2 – centre beam, 3 – seal, 5 – joist box, 6 – prestress element, 7 – bearing, 8 – stirrup, 9 – crossbeam.

Nowadays the most popular are nosing and modular as well as cantilever expansion joints, the latter also as supported ones. Some years ago environmental requirements put in evidence the noise limitation necessity. That was the reason of wide use of noise reducing elements combined mostly with nosing and modular expansion joints. These elements play a decisive role in health condition of whole devices. They are very vulnerable on dynamic and fatigue behavior. In ETAG 032 the problem of working life is treated as one of the most essentials. It depends on: traffic loads, imposed movements, frequency and number of cycles, as well as on fatigue resistance and wear of their components. It depends also on component's replacement possibility and quality of installation. Declared by manufacturer, the product durability should be based on the durability categories considering acc. to EN 1337-2

(Table 4.6) number of trucks N_{obs} = 0.5 mln per year. There are 4 working life categories from 10 to 50 years. ETAG 032 distinguishes also 3 component's categories depending on the possibility of their replacement: A (nonreplaceable), B (replaceable with major obstruction of the traffic flow) and C (replaceable with minor obstruction of the traffic flow). The working life should be at least on the level of 10 years.

Before introducing to the market the new expansion joints should be verified during type tests in a notified laboratory. These tests are based on fatigue loading simulating traffic loads and movements ≥ 0.2 mm/h due to thermal expansion or/and ≥ 0.6 mm/s due to traffic loads. There are two load models with contact pressure of 0.8 N/mm² and 1.0 N/mm². The number of cycles depends on desired durability category: 10, 15, 25 or 50 years. In ETAG 032 (Fig. 19) and other national guidelines the requirements for installation admissible tolerances are given.

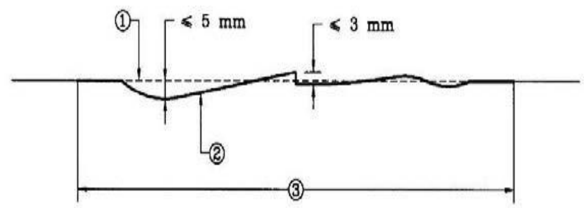


Fig. 4.7. Admissible level differences in running surface; 1 – ideal surface line, 2 – running surface of the joint, 3 – expansion joint zone.

In Poland, since 2008 especially on new motorways, we register many damages or failures with nosing and modular expansion joints. In most cases they were equipped with noise reducing elements. Some of them were damaged after only one year of service. The problem was with attachment of these elements to intermediate beams using improper bolts. This design didn't respect requirements of PN-EN 1993-1-8 concerning joints subjected to vibrations, chocks or others dynamic actions. There are not allowed bolts with conic shape head. Also PN-EN 1090-2+A1:2012 do not advice threaded bolts with respect to effect of threads plastic behavior under dynamic loads.

VI. METHODOLOGY

BEARING RIGIDITY THEORY: FUNDAMENTALS AND DEVELOPMENTS

Bearing Rigidity and Its Significance

Bearing rigidity theory addresses the fundamental question of when a framework's configuration can be uniquely determined (up to translation and scaling) using only the bearings i.e., the relative direction between neighboring agents or nodes. Unlike distance rigidity, which relies on fixed inter-agent distances, bearing rigidity exploits directional information, offering advantages in scenarios where distance measurement is costly orimpractical (Zhao & Zelazo, 2015).

The extension of bearing rigidity from two-dimensional (2D) frameworks to arbitrary dimensions represents a major advancement. Zhao and Zelazo (2015) demonstrated that a framework in any dimension is uniquely determined by inter-neighbor bearings if and only if it is infinitesimally bearing rigid. Infinitesimal bearing rigidity implies that all infinitesimal motions pre-serving the set of bearings are trivial, corresponding only to translations and uniform scaling. This theoretical foundation is not only essential for stability analysis in multi-agent formation control but also underpins practical algorithms for distributed control and localization in robotics and sensor networks.

GRAPH-THEORETIC CHARACTERIZATIONS AND GENERIC BEARING RIGIDITY

Bearings in networked systems are naturally represented using graphs, where vertices correspond to agents or structural nodes, and edges represent bearing constraints. The notion of generic bearing rigidity introduced by Zhao et al. (2017) emphasizes that bearing rigidity is determined by the underlying graph's structure rather than specific node positions. A graph is generically bearing rigid if, for almost all configurations, the associated network is bearing rigid. Laman graphs are central to this characterization. Originally known from distance rigidity theory for 2D frameworks, Laman graphs are defined by having exactly (2n-3) edges for (n) vertices, with every subset of (k) vertices spanning at most (2k-3) edges. Zhao et al. (2017) proved that Laman graphs are generically bearing rigid in any dimension, ensuring that networks constructed from such graphs are bearing rigid for almost all node configurations. This result is significant for the design and analysis of robust formations in both structural and control contexts.

Moreover, the bearing Laplacian matrix provides a matrix-weighted extension of the traditional graph Laplacian, crucial for analyzing rigidity and stability properties. In undirected graphs, the null space of the bearing Laplacian coincides with that of the bearing rigidity matrix, underpinning the equivalence between infinitesimal bearing rigidity and global rigidity (Sun, Zhao, & Zelazo, 2023).

BEARING EQUIVALENCE IN DIRECTED AND UNDIRECTED GRAPHS

The extension of bearing rigidity concepts to directed graphs introduces additional complexity. In directed graphs, the bearing Laplacian is typically non-symmetric, and the equivalence between the null spaces of the bearing rigidity and Laplacian matrices no longer holds universally. Sun et al. (2023) introduced the concept of bearing kernel equivalence for directed graphs, stipulating that a formation is bearing equivalent if both matrices share a null space spanned only by translations and scalings. The spectral properties of the bearing Laplacian, such as the sign and multiplicity of its eigen-values, become critical in characterizing the stability and rigidity of directed formations.

BEARING FAULT DIAGNOSIS: DATA-DRIVEN APPROACHES

The Importance of Bearing Health Monitoring

Bearings are critical in rotary machinery, with bearing failures accounting for a substantial proportion of mechanical breakdowns. Traditional diagnostic methods, such as Fourier analysis and manual feature extraction, often struggle with complex fault types and require significant domain expertise (Yu et al., 2022). The rise of industrial big data and the Industrial Internet of Things (IIoT) has fueled the adoption of deep learning for automated, scalable fault diagnosis.

Multi-Size Kernel Adaptive Convolutional Neural Networks

Yu et al. (2022) proposed a multi-size kernel based adaptive convolutional neural network (MSKACNN) for bearing fault diagnosis, addressing the limitations of conventional approaches. The MSKACNN directly processes raw vibration signals to automatically extract hierarchical features associated with various bearing faults, including challenging conditions such as ball mixing—a production defect involving balls of varying sizes.

Key innovations of MSKACNN include: - Multi-size convolutional kernels in early layers, capturing both high- and low-frequency features.
Adaptive batch normalization and dropout layers to enhance generalization and adaptability to varying operational conditions. Lightweight, real-time implementation suitable for deployment in production environments.
Experimental results demonstrated that MSKACNN outperforms state of-the-art alternatives in both accuracy and generalization, as validated on proprietary and benchmark datasets. This data-driven approach exemplifies how advances in machine learning complement theoretical developments in bearing rigidity, providing robust tools for condition-based monitoring.

Expansion Joints: Assessment and Monitoring in Bridge Engineering
Expansion Joint Function and Challenges
Expansion joints are crucial for accommodating movements in civil structures, particularly bridges, due to temperature fluctuations, load variations, and other dynamic effects. Their proper functioning ensures structural integrity and user comfort by preventing unwanted stresses and accommodating movement. However, expansion joints are also sources of noise emissions and can degrade over time, posing challenges for maintenance and assessment (Ryjáček et al., 2025).

Non-Contact Assessment Methodologies
Traditional methods for assessing expansion joint condition, such as manual measurement of geometry and gap size, often require traffic interruption and expose inspectors to risk. Ryjáček et al. (2025) introduced a non-contact, operational methodology utilizing crossing laser sensors, CPX (close proximity) acoustic sensors, and advanced data collection and evaluation techniques. This system enables: - Rapid, high-resolution scanning of joint geometry and noise emission at speeds up to 90 km/h without traffic interruption. - Automated data processing capable of monitoring long-term trends in degradation and noise over extensive bridge networks. - Integration with acoustic measurements following standards such as EN ISO 11819-2, linking structural condition directly to environmental and user impacts. An exemplary innovation is the "EJ Passport," a comprehensive, data driven record of each expansion joint's geometric profile, noise emission,and defect status. Furthermore, the integration of IoT-based camera systems for online defect detection allows for real-time monitoring and proactive maintenance, mitigating the risk of sudden failures.

Statistical Trends and Maintenance Implications
A detailed database of expansion joints across Czechia reveals that while the majority are in good condition, a notable percentage display significant defects, particularly among older joints (Ryjáček et al., 2025). The adoption of automated, non-contact assessment methods facilitates objective comparison across different joint types and monitoring of degradation over time, supporting evidence-based maintenance strategies.

Intersections and Implications
The intersection of theoretical advances in bearing rigidity, data-driven diagnostic methods, and innovative expansion joint assessment techniques reflects a broader trend in engineering toward integrated, intelligent infrastructure. Rigidity theory informs the design and analysis of both mechanical and structural systems, ensuring stability and uniqueness in configurations. Machine learning enhances our ability to detect and classify faults, while modern sensing and data acquisition technologies enable rapid, large-scale monitoring of critical components.

For practitioners, these advances translate into improved reliability, reduced maintenance costs, and enhanced safety. For researchers, the theoretical frameworks of bearing rigidity and equivalence continue toc inspire new algorithms and assessment methodologies, bridging the gap between abstract mathematical concepts and tangible engineering applications.

VII.CONCLUSION

Bearings and expansion joints are indispensable in ensuring the functionality and longevity of machinery and civil structures. Recent research demonstrates significant progress in both the theoretical understanding of bearing rigidity and the practical assessment of bearing health and expansion joint condition. The synergy between graph-theoretic rigidity analysis, machine learning-based fault diagnosis, and non-contact structural evaluation methods sets the stage for more resilient and intelligent

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