Control Tests of Long-Span Laminated Timber Structures with Nodes on the Glued-In Rods

Aleksandr Pogoreltsev

Abstract Large-span laminated wooden structures have large dimensions and require the creation of knots and joints to divide the structures into technological elements, convenient for manufacturing and installation. This problem is solved by using both traditional and new types of knot joints.

New types of knots include connections on glued rods. If in Europe there was the way to create knots with rods glued along the fiber of the wood, or along and across the fiber, in Russia the focus was on the knots of laminated wooden structures with reinforcing rods glued at an angle to the fiber of the wood.

Under the leadership of S.B. Turkovsky the systems of knotted connections on glued rods - "CNIISK systems" were developed. Hundreds of objects were built using this system.

Such objects often require control tests. In most cases, the tests are not performed on structures, but on fragments with assemblies in full size. The rationale and purpose of control tests are given.

Examples of control tests during the construction of long-span buildings and structures with glued wood frameworks, carried out by the laboratory of wooden structures of the Kucherenko Central Research Institute of Scientific and Technical Cybernetics under the guidance of V.A. Kucherenko Institute of Wooden Architecture and Construction are given.

Keywords Large-Span Wooden Structure · Control Tests · Glued Reinforcing Bar · Knot

1 Introduction

Glued wood structures combine lightness, strength, aesthetics, corrosion resistance and other positive characteristics. They allow you to implement a variety of architectural forms and gives an expressive visual effect in combination with other

---

A. Pogoreltsev (✉)
JSC Research Center Construction (Kucherenko TSNIISK), Moscow, Russia

N. Vatin et al. (eds.), *Proceedings of MPCPE 2022*, Lecture Notes in Civil Engineering 335, https://doi.org/10.1007/978-3-031-30570-2_11

modern building materials. Glued laminated wooden structures are widely used in construction of long-span buildings and constructions.

Elements of large-span laminated wooden constructions can have a great length, which causes difficulties in production and transportation. Especially it concerns bent laminated elements of arches, frames, meridional ribs of domes and other constructions.

There is a necessity to divide long structures into technological elements with implementation of consolidating rigid joints.

A typical solution adopted in Europe is the use of rigid joints with dowels or screws [1], including nodes with steel pads and spacers.

In the second half of the last century the research and practical application of wooden structure joints on glued rods began.

The first application of steel rods glued into the wood along the fibers in the nodes was proposed in the SoyuzDorNII [2]. Later, similar structural solutions were widely investigated abroad [3, 4] and others.

Abroad, the study of knots paid more attention to rods with metric threads along the entire length, glued along the fibers [5–7], and those glued at an angle to the fibers were considered to strengthen wooden constructions [8, 9]. In the USSR and later in Russia, the corrugated reinforcement rods for reinforced concrete structures, glued at an angle to the fibers, were considered first of all for the joints.

The first tests of the rigid beam joint on angled glued rods were carried out by S. B. Turkovsky in 1975. Although the joint was located in the area of maximum bending moment, the failure of the beam occurred outside the joint.

The complex system of node joints of wooden structures on inclined glued rods - CNIISK system - was developed under the supervision of S.B. Turkovskiy [10–18]. A particular case of inclined glued rods were rods glued perpendicular to the fibers.

Hundreds of objects, including large-span ones, have been built using the “TSNIISK system” [19].

2 Control Tests

When designing large-span laminated timber structures with nodes on glued rods, it is sometimes necessary to conduct control tests. The justification for the necessity of testing QDC nodes is as follows:

- structures of unique structures with spans over 100 m, heights over 100 m, with cantilevered structures over 20 m;
- buildings and structures of especially hazardous and technically complex objects, the list or classification of which is established by the national legislation;
- Buildings and constructions with design and construction using brand new design solutions and technologies which have not been tested in construction practice and operation (experimental designs);
- nodes of critical structures in the process of mastering the production;

– large-span structures with manufacturing and (or) assembly defects.

The reasons for the necessity of control tests of glued wood constructions with nodes on the glued rods are often the set of the reasons described above.

Control tests of full-size long-span structures are carried out in rare cases. Usually the bearing capacity of such structures is determined by the bearing capacity of nodes. Therefore, tests are performed on the most loaded or poorly studied nodes. The test objectives are determined depending on the reason for the verification tests:

- Determining the bearing capacity of a structure or assembly in the absence of standard calculation methods;
- assessment of the correctness of the design solutions and calculation assumptions;
- verification of manufacturability of nodes on glued rods;
- quality control of structural fabrication;
- Verification of assemblage ability and quality control during assembly;
- expert evaluation of causes of structural failures.

Often the control tests are complex and include several objectives. When testing by the specialists of V.A. Kucherenko Central Research Institute of Nuclear Power Engineering, there are always additional objectives - issues of research on the operation of knotted joints on glued rods.

3 Examples of Control Tests

Let’s consider the experience of the control tests conducted by the staff of the Central Research Institute of Building Research named after V.A. Kucherenko.

3.1 The Main Building of the Country Hotel in the Village of Lipki

The three-story building has a near-circular shape in plan and is blocked by multispan beams set at radii with a 2.8º slope on straight sections. The largest diameter of the building is about 100 m.

All roofing girders were made of unified elements with 140 × 1100 mm cross-section, up to 20 m long, supplied at the factory with embedded parts of the same type at the ends, which turned these elements into continuous multispan beams by means of welding at assembling (see Fig. 1). Slanted glued rods with a gluing depth greater than the design depth were used to anchor the support plates. This ensured that the glued package was safeguarded against possible delamination and defects in the support areas, and compensated for some weakening of the glue joint during welding.

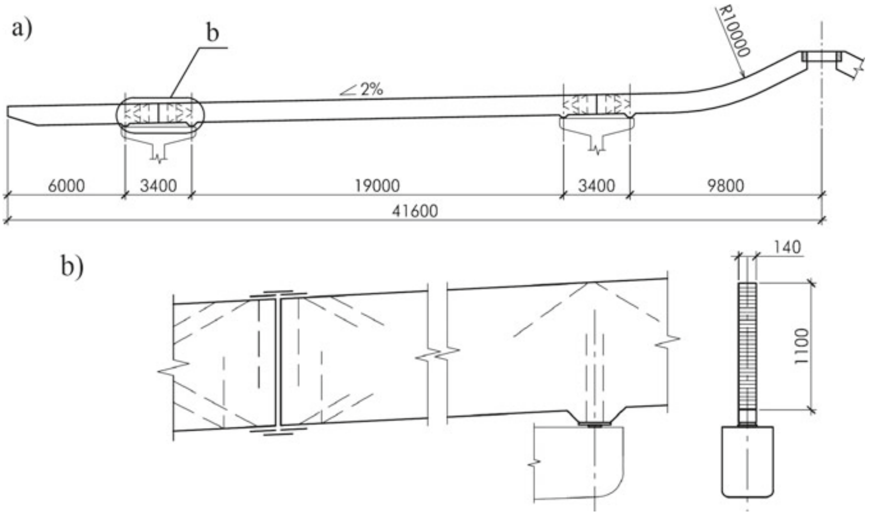

Fig. 1 Covering beams in Lipki: **(a)** scheme of the continuous multispan girder; **(b)** structural scheme of the rigid joint and support node

The most critical in the design of beams were the rigid joints on inclined glued rods, which were first used in the practice of large-span buildings construction. Since beams with joints were experimental designs and the Volokolamsk Factory was mastering the production of joints on inclined glued rods, control tests were conducted until the failure of the full-scale fragment with a rigid joint (see Fig. 2).

The joint failure was caused by the loss of stability of the steel butt-joint lining in the compressed zone with a load of more than 1.6 times higher than the design load, which, taking into account the test time, is more than required.

The general view of the coating at the installation stage is shown in Fig. 3.

3.2 Farms at the Manezh Exhibition Center, Moscow

The historical trusses of the Central Exhibition Hall (CEH) "Manezh" were designed and installed in 1817 by the Russian engineer A. A. Betancourt on the initiative and with the assistance of Emperor Alexander I.

The 48-m span trusses made of 260 × 350 mm beams and up to 10 m long were the finest engineering work of that time and were the first of their kind in the world to be registered with UNESCO as a great engineering achievement. On March 14, 2004, all wooden structures, including the unique trusses, were destroyed by fire.

At a meeting of the Architectural Council of Moscow, held soon after the fire, the task of restoring the Manezh Central Exhibition Hall was set. It took six months to

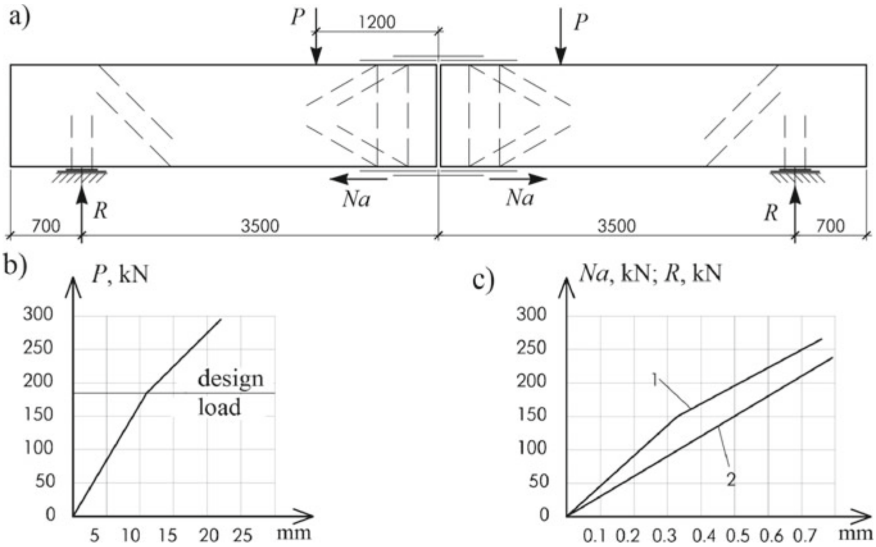

Fig. 2 Testing of a rigid joint: **(a)** an experimental fragment; **(b)** dependence of deflections in the middle of the span on the load *P*; dependence of the embedded part displacement on the force *Na* in it (1) and the movement of the support joint relative to the wood on the support reaction *R* (2)

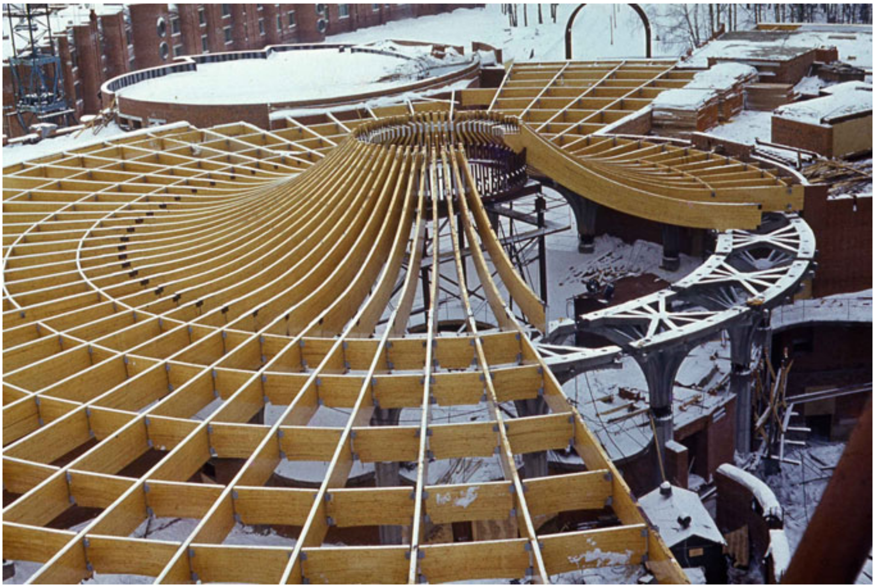

Fig. 3 General view of the coating at the installation stage

design, produce, assemble and install. The frames were to be made of glued wood preserving the structure, geometry and external similarity.

The project design was preceded by the experimental-design works on a variant selection, testing and refinement of manufacturing techniques of the most responsible truss components (supporting, ridge and bottom chord joints).

For the control tests, there was a prototype made in the form of a triangular sill-less truss with a span of about 8 m and the cross-sections and junctions of full-size (see Fig. 4). The support nodes of the model differed from each other in design. One node was made with a steel bottom chord as a stop on the end of the top chord. The other node was made according to “CNIISK system” in the form of a wooden chord with a steel support for the upper chord on V-shaped anchors - rods glued at angles of +45° and −45° to the direction of wood fibers of the lower chord. The ridge knot was also made on glued rods. The bottom chord consisted of two parts - one steel, the other wooden with a rigid joint on glued V-shaped anchors in the middle of the span.

The design load was 820 kN. The loading was carried out up to the collapse in a press equipped with a special traverse (see Fig. 4a).

At the first stage, loading was performed three times to the design load. The test results showed elastic operation of the assemblies.

Further testing was carried out until failure by stepwise increasing load. Failure occurred under 1200 kN load from loss of stability of curvilinear part of compressed, and rupture of tensile bonded rods of V-anchors in the support node stop. In other nodes and in the junction of the lower chord, there were no signs of failure, including in the ridge node, tested by a special method of one-sided load. The sufficient bearing capacity of the main nodes and joints was confirmed by experiment.

When designing the trusses, the support node, by which the collapse occurred, was rejected and the node with emphasis on the end of the upper chord was adopted. In October 2004, the installation of the new roof trusses was completed (see Fig. 5).

3.3 L-shaped Trusses with a Span of 48 m

In the Palace of Sports in Strogino in the covering of the main hall for figure skating the unique for its time (2005) lenticular trusses from laminated wood 48 m long were used (see Figs. 6 and 7).

In static terms, the lenticular trusses are characterized by almost identical forces in all panels of both chords along the length of the span. The forces in the lattice are relatively small. This greatly simplifies their design. But the greatest shear forces between the girders are concentrated in the support nodes, which traditional connections have not been able to absorb before, even for the mid-span trusses. The problem was solved by the use of connections on inclined glued rods.

Supporting rigid units of prefabricated truss liners with spans over 24 m are usually assembled in the factory. Joints of compressed and stretched chords and lattice nodes are assembled. Joints on the glue of the outermost elements of the upper and lower

Fig. 4 Control tests of the experimental sample of the TSVZ "Manezh" truss: **(a)** general view; **(b)** loss of stability of the compressed rod at failure; **(c)** rupture and pulling out of the stretched bar

chords with different directions of wood fibers are performed in the factory, are unreliable. The design assumes that the glue joint is delaminated. Along the joint, glue rods are installed obliquely to replace the glue joint.

When designing, it was taken into account that 48 m is the maximum span of trusses in Russia with wooden upper and lower chords. This caused the necessity of control tests. The purpose of tests were to evaluate the correctness of the taken design solutions and design assumptions, to check the manufacturing quality of glued wooden elements, to evaluate the deformability of tensile joints on inclined glued

Fig. 5 Assembly of the Manezh Central Exhibition Hall trusses

Fig. 6 Figure skating competition hall

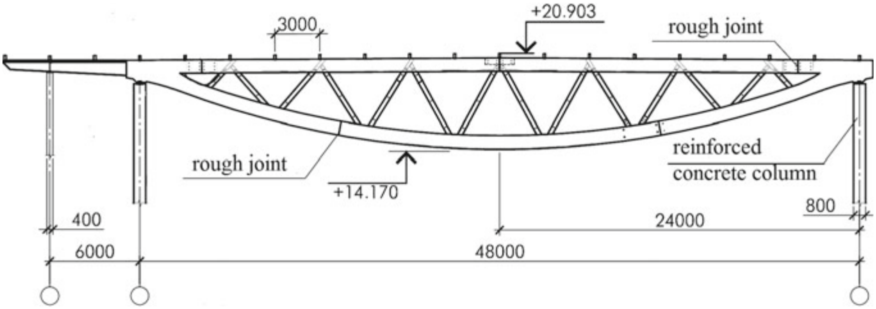

Fig. 7 Design diagram of a lenticular truss with a span of 48 m

rods, to study the stress–strain state of the junction zone of the upper and lower chords.

A block of two trusses taken from a set of fabricated structures having the largest number of manufacturing defects was subjected to the test (see Fig. 8a) [20]. The design load was 1500 kN. The loading mode was adopted as staggered by 20% of design load, which amounted to 300 kN. The loading was carried out by reinforced concrete foundation blocks and piles. At each stage, readings of deflectometers, strain gauges, and load cells glued in the supporting zone were recorded (see Fig. 8b).

When the load reached 1800 kN, or 1.2 of the design load, the welded joints of the bonded reinforcing bars and the steel plate in the support assembly failed. The assembly was strengthened without removing the load.

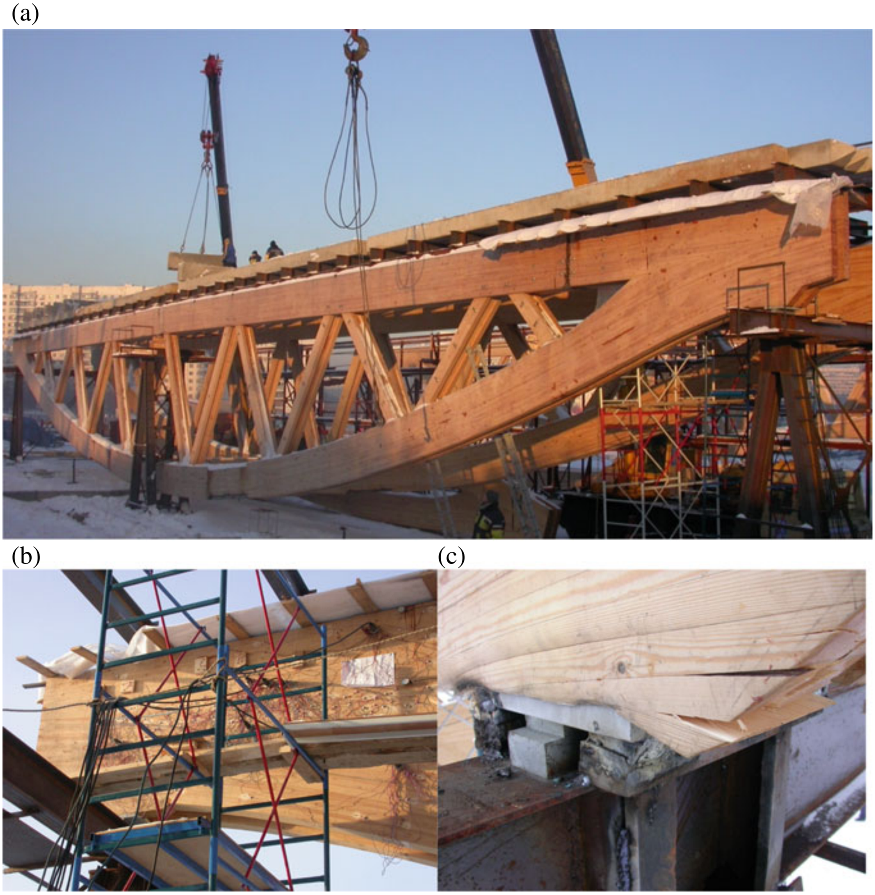

Fig. 8 Control tests of a block of two lenticular trusses with a span of 48 m: **(a)** general view in the process of loading; **(b)** load cells in the supporting zone; **(c)** pushing through the bars with subsequent crushing on the support

The tests were continued the next day. Failure occurred at a holding step of 2700 kN, or 1.8 of the design load. The cause of the failure was the penetration of the glued rods in the truss support node (Fig. 8c).

The test results showed that all the nodes on the glued rods, except for the support rods, met the load-carrying capacity requirements. Modifications were made to the support assemblies of all subsequent trusses to prevent failure of the welded joints.

4 Conclusion

Joints on glued rods including "CNIISK system" are an effective type of joints for large-span glued wooden constructions.

Conducting control tests of large-span structures and, first of all, control tests of knots make it possible to determine the actual load-bearing capacity, to confirm the correctness of the design decisions and calculation assumptions made, the quality of manufacturing, to assess the causes of structural failure, etc.

Such tests increase the safety of laminated wooden structures of critical buildings and constructions.

References

1. CEN EN 1995-1-1-2004 Eurocode 5: Design of timber structures - Part 1-1: General - Common rules and rules for buildings
2. Pospelov, I.D., Tumas, G.V.: On new glue joints of load-bearing elements of wooden bridge spans, Scientific report. SoyuzDorNII, Moscow 43 (1970)
3. Duchoň, V., et al.: Experimental test of timber connections with glued-in rods in bending. Wood Res. **61**(4), 567–572 (2016)
4. Gaunt, D.: Joints in glulam using groups of epoxy-grouted steel bars. NZ Timber Des. J. **26**(1), 34–38 (1999)
5. Steiger, R., Gehri, E., Widmann, R.: Pull-out strength of axially loaded steel rods bonded in glulam parallel to the grain. Mater. Struct. **40**, 69–78 (2007)
6. Gerold, M.: Verbund von holz und gewindestangen aus stahl. Bautechnik **69**(4), 167–178 (1992)
7. Gustafsson, P.-J, Serrano, E., Aicher, S., Johansson, C.-J.: A strength design equation for glued-in rods. In: International RILEM Symposium on Joints in Timber Structures, pp. 323–332. Stuttgart (2001)
8. Steiger, R., et al.: Strengthening of timber structures with glued-in rods. Constr. Build. Mater. **97**, 90–105 (2015)
9. Jockwer, R., Serrano, E.: Glued-in rods as reinforcement for timber structural elements. In: Branco, J., Dietsch, P., Tannert, T. (eds.) Reinforcement of Timber Elements in Existing Structures: State-of-the-Art Report of the RILEM TC 245-RTE, pp. 29–49. Springer International Publishing, Cham (2021). https://doi.org/10.1007/978-3-030-67794-7_3
10. Turkovsky, S.B.: Designing of glued wood structures joints on glued-in bars. In: Proceedings of CIB-W18 Meeting 22, Berlin, Germany, Paper CIB-W18A/22-7-3 (1989)
11. Turkowsky, S.B., Lukyanov, E.I., Pogoreltsev, A.A.: Use of glued-in bars for reinforcement of wood structures. In: Report for International Timber Engineering Conference, 2–5 September 1991, London, UK, vol. 3, pp. 3212–3217 (1991)

12. Frolov, A.Y., Pranov, B.M., Naichuk, A.Y.: Deformability of joints on glued steel rods working on punching. Izv. Vuzov. Constr. Architect. **8**, 17–20 (1990)
13. Pogoreltsev, A.A.: Calculation of tension joints of laminated wood structures at pasted in bars. Struct. Mech. Anal. Constr. **4**(249), 28–33 (2013)
14. Turkowski, S., Pogorelcev, A.: Złącza konstrukcjidrewnianych na sworznie wklejane. In: Drewno I materiały drewnopochodne w konstrukcjach budowlanych. V konferencja naukowa. Referaty. Szczecin, 17–18 maja 2002 r, pp. 169–176. Politechnika Szczecińska–Szsecin (2002)
15. Naichuk, A., Pogoreltsev, A., Demchuk, I., Ivaniuk, A., Roshchina, S.: Rigid joint of bent glued laminated timber structures using inclined glued-in rods. In: Vatin, N., Roshchina, S., Serdjuks, D. (eds.) Proceedings of MPCPE 2021: Selected Papers, pp. 501–521. Springer International Publishing, Cham (2022). https://doi.org/10.1007/978-3-030-85236-8_45
16. Pogoreltsev, A.: Compressed knots on glued-in rods of wooden structures. In: Vatin, N., Roshchina, S., Serdjuks, D. (eds.) Proceedings of MPCPE 2021: Selected Papers, pp. 337–347. Springer International Publishing, Cham (2022). https://doi.org/10.1007/978-3-030-85236-8_31
17. Pogoreltsev, A.A.: Numerical studies of glued wooden beams with inclined reinforcement. In: Collection of Scientific Works. V.A. Kucherenko Central Research Institute of Construction Materials, pp. 97–100 (1989)
18. Turkowski, S., Pogorelcev, A.: Złącza konstrukcjidrewnianych na sworznie wklejane. In: Drewno I materiały drewnopochodne w konstrukcjach budowlanych. V konferencja naukowa. Referaty. Szczecin, 17–18 maja 2002 r, pp. 169–176. Politechnika Szczecińska. – Szsecin (2002)
19. Turkovsky, S.B., Pogoreltsev, A.A., Preobrazhenskaya, I.P.: Glued Wooden Structures with Knots on Glued-in Rods in Modern Construction (TsNIISK System). RIF Building Materials, Moscow (2013)
20. Gorpinchenko, V.M., Pogorel'tsev, A.A., Ecknadosyan, I.L.: Large-scale tests provided for a block, consisting of two wooden lens-type roof trusses of the sports complex 'Strogino'. Promyshlennoe i Grazhdanskoe Stroitel'stvo **8**, 38–39 (2005)